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SELF-PURIFICATION OF FLOWING WATER AND THE INFLUENCE OF POLLUTED WATER IN THE CAUSATION OF DISEASE.*

(A BIOLOGICAL STUDY.)

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WITH DISCUSSION.

Our water sheds being in great part composed of diluvial and alluvial formation can, besides holding much in the depression of their uneven surfaces, take up and retain a varying amount of the water precipitated from the clouds, or coming directly from condensation of atmospheric vapor or otherwise reaching the earth. It may be considered that dry, sandy soil takes up 45 per cent. of its volume of water ;† while dried turf can absorb perhaps ten times its weight of water by reason of the great surface created by the enormous number of minute particles. The finely divided elements of the soil can furthermore, by their capillarity, cause water to rise through their substance to a considerable

* Read before the American Society of Civil Engineers, November 5th, 1890.

The first pages are introductory, and added chiefly as a succinct reply to questions propounded by members of the Society at the time of the reading of the paper. For brief explanation of the bacteriology involved, see Appendix (page 42).

† Meister : Soyka, *Der Boden*, page 83.

height, which in loam is many times greater (though the rise is there much slower) than in the coarsest earth (gravel). The hydrostatic power of earth is much augmented by the presence in it of organic matter,* and the cleaner the ground is kept the drier it is.

More or less deep in permeable earth, underlain with impermeable strata, water is regularly found completely filling all the pores, and this is called the "ground-water." Not to explain at length the zonal differences of the layer of earth between the surface of the ground and the surface of the ground-water, it may be said briefly that water passes rapidly through this when of coarse gravel, while in very fine soils many months may in our region be required for a given water to make its way from the air down to the surface of the ground-water. By taking up certain constituents and losing others it may have considerably changed its character in the downward passage. Most varieties of the micro-organisms which swarm on and near the surface of the ground are less able to find the conditions favorable to their life and activity after descending a few feet. Some porous soils seem to be permeable to bacteria for less than 6 feet. Hence the ground-water is often quite free from bacteria. The best deep springs show few or none of these, and the uncontaminated water flowing directly thence is, unless highly impregnated with minerals, the most wholesome of beverages.

These underground bodies of water may be regarded as subterranean lakes or water-courses, usually flowing several feet daily toward the streams or lakes draining the basins in which they are, and the level of the ground-water is lowest near such draining streams or bodies of water. Hess† found that in northern Germany such water moved sometimes more than 100 feet per day. Thiem‡ judged from observations on the Bavarian plateau that from 9 to 25 feet was an accurate estimate of the daily advance of the ground-water there measured. It is largely owing to such enormous and well-protected reserves that the lakes and streams of our region maintain the average level to which they tend to return when temporarily lowered by drought or when swollen by freshets.

For about thirty-five years, since first v. Buhl and Seidel called attention to the principle, v. Pettenkofer and others have insisted upon what they consider the causal relations existing between the moisture changes indicated by the varying height of the ground-water

* Hoffmann: *Archiv für Hygiene*, II, 145.

† *Zeitschrift des Architekten und Ingenieur Vereins* in Hannover, XVI.

‡ *Journal für Gasbeleuchtung und Wasserversorgung.* 1880.

level and the prevalence of epidemics which, they claim, are not much if at all, influenced by purity of drinking water as such, by mere filth or any other than this particular element which induces the manifestations of activity on the part of the causative germ. Soyka's experiments* led him to consider that in a long, dry spell of weather, such as precedes the lowering of the ground-water level, there is a more or less uninterrupted capillary flow towards the surface. With this, living micro-organisms that may be in the ground are carried upward into the outer layers of the soil. From the evaporation of this water the microbes remain on the surface or somewhat deeper. With rain they may be washed along or return into the ground. If dry weather persist, they may be stirred up with the dust and in their exsiccated form carried far through the air, as has been rendered evident by several examinations where they have been found many miles out above the open ocean. After the evaporation of water coming up to the surface, the previously-dissolved substances remain in the upper layers of the ground, and the water there becomes a more concentrated solution of these substances. The ground-water is in itself quite harmless. Its significance is as an indicator of the fluctuation in the moisture of the ground, and the cleaner the earth is kept the less importance is attached to hydrometric changes.† While it is not denied that germs may have to be present to cause the disease, this doctrine claims that they can produce disease only when the local conditions favor their activity.‡

Repeated and careful observations have made those of the Munich school who contend for this "localistic" theory insist that, excepting, of course, where by artificial drainage we intentionally cause water to be drawn away from the ground, such a disease as, for instance, typhoid fever, increases as the ground-water sinks, and no considerable epidemic of typhoid occurs without at the same time a sinking of the ground-water level. No considerable typhoid epidemic occurs in the period of a large rise of the ground-water, say the champions of the interpretations which v. Pettenkofer has given to the facts as observed at Munich.|| This view is, however, not in consonance with the facts of all epidemics.

The majority of practical hygienists do not indorse these views in their fullness. The definite advances made of late years by biological

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* Prager med. *Wochenschrift*, 1885.

† Dr. Max v. Pettenkofer: Deutsche med. *Wochenschrift*, Nov. 28, 1889, page 977.

‡ Dr. Mex v. Pettenkofer: *Archiv für Hygiene*, iv, 249; v, 353.

|| Prof. J. Soyka: *Archiv für Hygiene*, vi, 257.

study have given further and further ground for believing that, among other diseases, such ones as typhoid and probably cholera are solely caused by the vital activity (within the human organism) of the specific bacteria of these diseases. Inasmuch as a great number of sporadic and epidemic attacks of these scourges have been clearly traced to the consumption of water containing the infective elements of these diseases, and no other factor has there been constant or frequent, this belief is called the "drinking-water theory." While emphasizing the baneful effect of polluted drinking-water, it is of course admitted that unclean ingesta or anything that introduces these living bacteria into the alimentary canal, may be the means of carrying the infection into the system.

In the case of cholera the localistic theory seems more difficult to refute than in the case of typhoid. Yet in India, as elsewhere at the time of each epidemic, much circumstantial evidence has accumulated to make us suspect that the presence of the infective element in the alimentary canal is the prime factor in inducing the disease. Bacteriology has strengthened this opinion from the time when Koch* found the peculiar spirillum in cholera dejecta and in the intestines of those who had died from cholera. The presence of this characteristic micro-organism in the water of a certain tank was demonstrated by him, together with the fact that in the neighborhood in question, only those who had drunk of this water had the disease. The facts were presented with Koch's unsurpassed precision, and carried more conviction than any single one of the various similar histories. Still no theory suffices to explain the exemption of certain cities (as Stuttgart, Salsburg, Innsbruck, Hanover, Versailles, Rouen, Lyons, and others) from any outbreak during the various epidemics. These important centers of travel and commercial intercourse did not succeed in barring all entrance of infection, and their supplies of potable water were not conspicuously superior.

On page 211 of Koch's report (1887), an impressive diagram is given to show the permanently decreased cholera mortality in Calcutta since November 1st, 1869, from which time the city has been supplied with hydrant-water which, on analysis, seems very good. The tank water formerly used in the city (as even now in the suburbs) was—like nearly

* Bericht über die Thätigkeit der zur Erforschung der Cholera im Jahre, 1883, Entsandten Commission, page 182. Berlin, 1887.

everything in India*—exceedingly filthy. The water of the polluted Hoogly River, likewise more used formerly than at present, contained 250 000 bacteria per c.c. when examined by Koch.

Among those who consider that intelligent admission of ignorance is preferable to subserviency to a theory, it is proper here (because of his great and favorable opportunities for many years of observing cholera in its endemic haunts) to mention the statements of Surgeon-General Cunningham.† He observed that some districts in India are wholly immune at all times, regardless of the contaminated state of the water supplies. In his experience, disinfection of cholera dejecta is useless, and drinking-water does not cause cholera. Unlike some who have never been near India, or have not remained there for many weeks, he considers that railways have not in any way influenced the spread of epidemics of cholera in India either in time, place, or extent. It is needless to say that others dispute the accuracy of these inferences, and there is a great amount of evidence on both sides.

Selecting then the best portions from these conflicting theories, we find that both condemn a drinking-water having many‡ and various bacteria, and both call for abundant supplies of good water for individual and public uses. At the last International Congress, in Vienna, in 1887, where the leading hygienists of the world were gathered—and among them the high priests and acolytes of the ground-water theory—there was an unanimous and unmistakable expression of the opinion that, in order to the maintenance of a high degree of health, cities need an abundant supply of the purest water attainable by them.

The green algæ and the diatomaceæ are found only in waters well supplied with light and air, with no excess of organic matters, and free from regular sources of infection. But the written and oral expression of the opinions of others familiar with the subject, as well as an extensive personal observation, leads me to believe that a water containing a large number of bacteria, especially if many varieties are detectable in it, is objectionable as a beverage so long as it has not undergone the sterilizing influence of heat, or of other adequate means of purification. No sufficiently prolonged and repeated clinical observations by medically-qualified workers have yet accumulated, to determine just what harm, if any, the ordinary earth (and water) bacteria can produce when extensively consumed by human beings. Most of these micro-organisms are classed as harmless.

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* J. B. Hamilton, M.D., *British Med. Journal*, October 4th, 1890, p. 787. (Enteric fever in India.)

† Cholera. What can the State do to prevent it? By J. M. Cunningham, M.D., etc. Calcutta, 1884.

‡ Even in Emmerich und Trillich's Book, München, 1889, page 168, we find this admitted.

Unlike pathologists in some other countries, we do not here so often detect the ova of tænia and other intestinal parasites as having come from the ordinary water supply;* and although we here, of course, recognize that some nematodes develop first in water, and are thence carried to man, we are not confronted with such unpleasant statistics as Sievers derived from his obductions in Kiel.†

From the time when Dr. Michel‡ first called attention to the influence of contaminated water in causing typhoid fever (1855), and Snow in 1848, said that cholera was due to the use of infected water, an enormous mass of evidence has been constantly accumulating and has caused nearly all physicians among us to believe that such influence has usually been operative in those cases that they have met, even if for various reasons the exact source of the infection could not be traced. Furthermore, numerous attacks of diarrhœal disorders have been explainable in no other way.

Endorsing Naegele, the botanist, and other partisans of the extreme ground-water theory, Emmerich‖ performed a series of experiments upon animals, and from these inferred that decomposing organic matter taken with water into the stomach could not cause harmful symptoms. As evidence of his sincerity he daily, for two weeks, drank from one to two pints of very foul water taken from a hospital brook, which to the naked eye and to chemical tests was distinctly infected with sewage and which showed a large amount of chlorides, ammonia, and various organic substances. During the first three days he noticed slight gastritis, yet during the remainder of the fortnight no ill-effects were recognized. A month later, having acquired a gastro-enteritis, he again tested upon himself in the same way the effect of the same sort of water but observed no detriment to his health. Very few could be induced to repeat such unpleasant subjective experiments, and many such would only prove that polluted waters vary in character and are not at all times, and under all circumstances, demonstrably harmful. Most persons would, if solely for æsthetic reasons, strongly object to drinking freshly-polluted waters.

Prof. Chandler calls my attention to the immunity of Albany, N. Y. (during the last two decades), from any serious outbreak of disease attributable to bad drinking-water, although the Hudson River, supplying water for its hydrants, is at times contaminated with the city's own sewage and certainly with that of the neighboring city of Troy. I have never investigated the water supplied to Albany, but am not surprised to hear (from those who have inquired) that the citizens regard the water with suspicion and suspect it of causing diarrhœal and other disorders.¶ It would seem as though cholera germs getting into such a water would greatly augment the danger of a cholera epidemic.

The experiments of Prof. J. v. Fodor§ show that unless steril-

* Knoch: *Virchow's Archiv*, xxiv, 453.
Blanchard: *Revue d'Hygiène et de police sanitaire*, le 20 Sept. & le 20 Oct., 1890.

† Sievers: Schmarotzerstatistik, Kiel, 1887.

‡ See *Annales d'Hygiène Publique*, etc., Dec., 1889, page 541.

‖ *Zeitschrift für Biologie*, xiv, 563.

¶ See New York City papers of Jan. 25, 1891, for mention of typhoid epidemic at Albany caused by drinking river water.

§ *Archiv für Hygiene*, iii, 118.

ized, as by boiling, foul waters may be assumed to be dangerous, even if not obviously so; for they tend to cause some degree of putrid infection which, however vague, may, like extreme hunger* and other "cachexies" act to weaken the system and render it less resistant to infection. Besides abundant laboratory evidence of this sort, the most impressive of tests have unintentionally, but in general with apparently very serious results, been made by so many bodies of men and communities that the mere enumeration would cover many pages. When more than one-tenth part of a population is attacked by typhoid after drinking of the water from a presumably pure mountain stream, stored for consumption, but into which a small amount of typhoid dejecta had been introduced (to cite the familiar experience of Plymouth five years ago); the fact that the majority of those using the same water, perhaps uncooked, revealed no symptoms of the malady, does not invalidate our right to interpret these epidemics by the light of our present knowledge and so infer that a polluted drinking water may be very dangerous. If Vienna, paralleling London's well-known experiences with cholera and typhoid, averaged many times the number of deaths from typhoid when she supplied her people with the water of the swift, "blonde" Danube, that she has had since the hill-spring supply has been furnished, the fact is very significant. But here, too, v. Pettenkofer has come forward with his keen interpretation of the facts and has tried to show that infected water had nothing to do with the causation of the disease.

There are a few authentic laboratory experiments† which go to show that, in ordinary water, disease-producing bacteria are, at least in some cases, more or less speedily destroyed by the hardier saprophytic varieties that abound in all supplies of doubtful quality. But since first Moers‡ found the bacillus of typhoid in water suspected of having caused the disease (the finding receiving Prof. Gaertner's confirmation when it was later questioned) and Michael|| likewise detected these (under corresponding circumstances and was endorsed by Prof. Johne),

* Canalis und B. Morpurgo, Fortschritte der Medicin, Sept. 15 and Oct. 1, 1890.

† Arnould: *Revue d'Hygiène*, ix, 27. Freudenreich: Annales de l'Institut Pasteur, iii, 200. De Giaxa: *Zeitschrift für Hygiene*, vi, 102; Annales de Micrographie, 1890. Garré: *Correspondenzblatt der Schweizer Aerzte*, 1887. Karlinski: *Archiv für Hygiene*, 1889, 113-432; also 1890, page 464. Kraus; *Archiv für Hygiene*, 1887, 205. Zagari: Giornale internazionale delle scienze mediche, ix.

‡ Ergänzungshefte zum *Centralblatt* für allgem. Gesundheitspflege, ii, 2, 144 (in 1886).

|| Fortschritte der Medicin, iv, ii, 353 (in 1886).

For list of some others who have detected the genuine typhoid germ in suspected water, see Uffelmann's Jahresbericht, 1890, page 224.

a considerable number of competent bacteriologists have in different countries reported similar results. Others have verified these facts by adequate laboratory trials. So we are to-day allowed to believe that the micro-organisms which cause some diseases can, despite the antagonistic influence of ordinary bacteria and influenced by various conditions which we as yet do not clearly understand, live at times for at least several days in natural and artificial waters of varying degrees of purity and still retain enough of their specific vitality to induce more or less serious cases of disease. The terrestrial conditions influencing the activity of these presumable causes have not yet been established with sufficient accuracy.

Chemistry affords us no sufficient test of the freedom of a water from the infective principles which cause serious diseases or which lessen the sum total of the vital forces and increase the susceptibility to infection. Yet, in lack of sufficient biological study of the question of self-purification of polluted sources of water-supply, the extensive and valuable reports of chemical examinations of numerous streams are very interesting and instructive.

Quite contradictory in their conclusions to almost all others, the eminent investigators engaged on the work done by the famous English Commission, in the years following 1868, asserted that no river, even in a course of more than 100 miles, became purified after pollution by organic matter. In all other countries the opinions are, and generally have been, that after flowing a number of miles from the place where sewage has entered, the river has chemically purified itself of at least a portion of the organic matters introduced. Thus the chemists connected with the investigation of the Seine waters found* that this river, after becoming very foul from receiving the sewage of Paris, purified itself in a flow of from 109 to 150 kilometers, so as to have returned to the same chemical quality that it had before reaching Paris. Of the numerous German presentations of similar facts that of Hulwa† is, like the repeated examination of the Isar at and below Munich, still more convincing. Hulwa found that the Oder, after receiving the sewage of Breslau, had completely purified itself chemically in a flow of 32 kilometers (or less than 20 miles). In this country the determinations of the late Prof. Wm. R. Nichols‡ made him conclude that various rivers of Massachusetts

* *Vierteljahrschrift für öff. Gesundheitspflege*, ix, 434. Durand-Claye: Assainissement de la Seine, Paris, 1885.

† Ergänzungshefte zum *Centralblatt* für allg. Gesundheitspflege, i, 68.

‡ Mass. State Board of Health Report, 1875.

went through a similar process. Very interesting in this regard are Long's* results, as he tested the changes in dilute sewage flowing from Chicago for miles down a canal. The element of considerable constant or irregular dilution is thus omitted till the Illinois River is reached. The oxidizing process causes the water to become much purer at Ottawa, after 80 miles of flow, and it is still purer at Peoria, 150 miles from Chicago. The most notable improvement Long found to be with respect to free ammonia, and the process was decidedly more active in summer than in winter.

Stagnant water and that standing in vessels, require much longer time than moving water to have a definite degree of oxidation take place in the organic substances present. Most chemists have been led to attribute a very great influence in this respect to the numerous bacteria which are found to be present in all sewage-contaminated waters. That the "nitrifying" varieties of these accomplish the work of oxygenation was first declared by A. Müller.† Emich‡ supported this theory by experiments in which he found that water purified itself chemically if many bacteria were present; but the same water sterilized by heating and kept germ-free did not improve chemically until, from exposure to the air, other bacteria had entered. Direct oxidization by the oxygen of the air did not take place, and the action of ozone and peroxide of hydrogen was less potent than that induced by bacterial activity. Heræus‖ studied the question and found that bacteria differed greatly in their activity in this direction. He got no oxidation with any of the few river and earth varieties that he tested. In England and in Massachusetts recent experiments furnish additional corroboration of this theory of the important function of nitrifying bacteria.§

Biological investigations into the self-purification of rivers have been very scanty and incomplete. Frank,¶ Prausnitz,** and Uffelmann,†† examining, respectively, the Spree, the Isar, and the Nebel, found that the number of bacteria present before the accession of the city sewage had increased with the addition of this polluting fluid. Within a dozen

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* *American Chemical Journal*, x, 26. London *Chemical News*, June 29, 1888.

† König, Berlin, 1887, page 99.

‡ *Monatshefte für Chemie*, vi, 77–94. *Chemisches Centralblatt*, 1885, 333.

‖ *Zeitschrift für Hygiene*, i, 193 and 213.

§ P. F. Frankland: *Journal of the Chemical Society*, 1888, No. 53, page 373. Massachusetts State Board of Health Report for 1888, supplement.

¶ *Zeitschrift für Hygiene*, iii, 355, ** München, 1890. †† *Vierteljahrschrift für öff. Gesundheitspflege*, xxii, 377.

miles or so of the place of the introduction of sewage, the water, even if biologically inferior, seemed usually not much worse than might have been the case if no city filth had contaminated the river. Schlatter* has recently reported that the Limmat usually purified itself bacteriologically to a marked degree within 9 miles after receiving the sewage of Zürich.

These and similarly executed observations are very important, even though the present methods of examination have not reached the degree of perfection (aimed at by Chantemesse, Holz, and others) that shall enable us to cultivate the morbific germs, present in a given example, by means of some ideal medium that at the same time suppresses any or all others, as we may elect. The commoner bacteria are, in general, hardier than the noxious ones and (as in the laboratory, so in nature) tend as a rule, to destroy these harmful ones, or at any rate, prevent their increase. Both kinds are exceedingly alike in many respects, and certain varieties of the harmless ones are very difficult for an expert to differentiate from well-known disease-producing varieties. Considering, therefore, the present status of practical bacteriology and its limitations, it seems a very fair test of the question whether rivers purify themselves from infection introduced, if we compare the numbers of germs found present in the water taken at different points. We can then reason from the figures and facts thus afforded. Hence, I herewith present data from some of the analyses which I have at various times been able to make. All have been done according to Koch's gelatine method, and—what is most important—all the waters have (unless the contrary is mentioned) each been "plated" within a few minutes after taking the samples, in sterilized bottles and with the utmost care, from the body of water. To keep the nutrient gelatine from melting when the prepared plates are exposed to warmth, I use a portable "cool chest," which allows the method to be successfully employed in summer, even amid the high heat of the "Great American Desert."

A swift, foaming mountain brook, that of the Kaaterskill "Clove," was tested at a part where it might have recently received the drainage of several hundred people, and where dilution seemed less conspicuously an obstacle to accuracy than would be expected in many parts of the brook's course. The ground was wet with rain which had fallen within twenty-four hours. Hence, the element of dilution and possibly

* *Zeitschrift für Hygiene*, ix, i, 56.

the entrance of new (surface) bacteria make the figures lack absolute value.

September 11th, 1890:	Bacteria in 1 c.c.
Brook in Catskills (after chance of pollution).........	54
Same brook 1½ miles further on (after 300 feet of irregular fall)..	49

Situated amid the most rugged and densely-wooded of mountains, Cœur d'Alène Lake supplies the Spokane River, which is tributary to the Columbia River. Pend d'Oreille Lake is in similar wild country, and its effluent stream enters the Columbia River in British America. The former lake was not tested, owing to the greater difficulty and delay involved in getting out from it—an element which could imperil the accuracy of the results. It probably has fewer bacteria than the lake given, which therefore answers here the purpose. The water was plated within five minutes of obtaining the sample 50 feet out in the lake, at a time shortly after a rainfall and in a portion near a small lumber camp.

June 10th, 1890 (clear):	Bacteria in 1 c.c.
River flowing into Pend d'Oreille Lake (rain on previous day)..	154
Pend d'Oreille Lake, highest number found*.........	43
Spokane River, 4 miles above Spokane Falls..........	69
" " just below city and falls (Spokane)...	129
" " 1 mile further down.................	125
Willamette River, 4 miles above Portland, Oregon....	44
Columbia River, 37 miles below Portland and 31 miles below confluence with Willamette................	52

The Mississippi affords in places excellent chances to study the question. The changes undergone by the decomposable elements of the vast quantities of logs and wood-refuse that the lumber industries cause to be present here, do not seem to cause nearly so great an increase in the number of bacteria present, as though the organic matter were wholly in the form of that coming from the surface drainage of agricultural districts and many habitations. This I have observed in the Ottawa River of Canada and in other parts of the North.

* This number was above that of the average of Western Lakes. Thus, Union Lake, upon which Seattle verges, averaged in the middle of its surface (June, 1890) only 13 germs per c.c. out of three analyses which I made of its waters.

Above the St. Anthony Falls the Mississippi has already drained a fairly populous portion of its valley. After passing over the falls the water receives sewage, then falls rapidly for a short distance, and in the next 10 miles does not appear to receive much other contamination. The time when the water was taken seemed very favorable for excluding any unusual degree of this, yet in view of the figures I am inclined to suspect some contamination not detected. The fact that the sample from St. Paul stood unplated for an hour may explain the number found. Even a passenger boat crossing up-stream may at times cause a decided increase in the number of bacteria in some parts of the current. This I know to my cost, from having thereby had a series of plates made at Sault Ste. Marie rendered unreliable for the purposes of this paper.

June 8th, 1890 (clear and sunny):	Bacteria in 1 c.c.
Mississippi River, above Minneapolis	620
" " just below Minneapolis	794
" " above St. Paul, 10 miles below former sample; no obvious source of pollution	843
(Last sample kept one hour before plating.)	

But for its short flow, the Passaic River furnishes every feature that could be desired for the study of this question. The northernmost tributaries furnish pure water in most parts. Between the junction with the Pequannock and the Great Falls at Paterson (6 or 7 miles) its way is through a rocky valley receiving relatively little drainage. In that distance, and with the Great Falls, the descent is 100 feet. Before the partial obliteration of the Little Falls, recently accomplished for economic agricultural reasons, I endeavored there to determine the influence of the violent agitation upon the number of micro-organisms in the stream before and after such action:

February 13th, 1889 (sunny and cold):	Bacteria in 1 c.c.
Lake Macopin, highest number found	57
Pequannock River (below a hamlet)	361
Passaic River, above Great Falls at Paterson (after draining 855 square miles)	573
Passaic River, below Great Falls in Paterson (near a mill)	1030 ±
Passaic River, below railway bridge (after receiving sewage)	2172
Water from Newark hydrant (supplied from lower Passaic River)	4000 ±

November 5th, 1889 (cloudy and cool):	Bacteria in 1 c.c.
Passaic River, ½ mile above Little Falls	372
" " 10 feet from rocky bank, just above falls	720
" " " " " " " " below "	704
" " Middle of Lincoln's bridge (5 miles down stream)	631
" " just above Great Falls	600 ±
" " just below " "	600 ±
" " Middle of railway bridge (after mingling of sewage)	1934
" " " " " " above Passaic	1907

[± Denotes partial liquefaction of plates such as to prevent absolutely precise determination.]

After leaving the region of Port Jervis the Delaware gradually enlarges, but regularly receives comparatively little objectionable drainage till Easton is reached at the junction of the Lehigh. Here it has mingled with it the more or less recent and diluted refuse of probably more than one hundred thousand people. All the way down to Trenton, over 50 miles further, the drainage is considerable and comes from a large area having many farms and numerous inhabitants. Thirty miles beyond Trenton, Philadelphia takes part of its water from this river after it has flowed from a water-shed supporting over half a million people.* My examination was made at a time when considerable rain had fallen in this valley during the previous three days, and the biological results must be numerically regarded as those of the river when at its worst. Various kinds of micro-organisms were detected in the water, including numerous "earth" and putrefactive bacteria. Among these were "Proteus" forms, which may be ranked among the objectionable varieties, yet† they are probably antagonistic to the germs of typhoid.‡

The Trenton water, said to be from the hydrant, and stored from the river several days previously, taken by me on the same day at the Pennsylvania Railway Station, had only a few hundred bacteria of five distinct harmless varieties. It was quite unlike the river water in character.

April 27th, 1889 (rainy, river swollen):	Bacteria in 1 c.c.
The usually excellent lake above Delaware Water Gap	1230
Delaware River at Water Gap	3400
" " above Easton	4270
Lehigh " " "	4925
" and Delaware mingled four miles below Easton,	10000 ±
Delaware River at Bridge near Trenton water intake,	20340

* See Report of Engineers Hering and Ludlow, Philadelphia Water Department, 1885.

† Hauser: Ueber Fäulnissbakterien, Leipzig, 1885. Bordoni-Uffreduzzi: *Zeitschrift für Hygiene*, iii, 333.

‡ Karlinski: *Archiv für Hygiene*, 1890, 473.

The following were at the same time collected by Philadelphia Health officer, and carefully kept cool till plated by me after four hours or more:

Delaware River, Philadelphia pumping station....	28000 ±
Schuylkill at Roxborough	43750 ±
" at Spring Garden......................	44456 ±

Under these unfavorable conditions, rivers, even in a sparsely settled region where there is little or no farming, may be expected to show an increase in the number of bacteria as the samples are taken further and further down the stream. This I have observed in several of the rivers of this State and elsewhere in the East, as well as in the Yellowstone Valley this summer on the occasion of a rainfall. Then the river at Glendive had more living germs in each cubic centimeter than were found at Billings, which is over 250 miles further up-stream.

The causes of the large proportion of cases of typhoid in Philadelphia, cannot be traced to any single source of infection. The water supply—if indeed the chief cause—may have received the dangerous germs at any place between the pumping-stations (in sewage-polluted tidal waters) and more or less remote tributaries. It is very difficult to prove that contagion can be carried many miles down a river, and many deny the possibility of this occurring. Owing to the use of contaminated milk by a number of families in Port Jervis, on the upper Delaware, a town of less than 10 000 inhabitants, the place had a slight epidemic of typhoid fever from October 1st, 1883, till the end of the year. No increase in the number of deaths from that disease in Philadelphia was recorded until January, 1884, when the total amounted to almost double the average for the same month during the preceding five years. From these facts one should not infer that the increase of the disease in Philadelphia was caused by the bacteria which had survived the 100 mile passage down the river, especially as in Trenton (which also takes water from the Delaware) there was, as I learn through the kindness of Dr. Ezra M. Hunt, no increase of this disease noted at the time. Still it seems highly probable that the health of the city would be improved, if all its water used for domestic purposes came from a remote location on this fine river, and were then conducted for many miles through an aqueduct. The deeper such aqueduct and its reservoir, the cooler would the water be in summer; and the more moderately cool pure water is, the more wholesome it is for the masses of a city's population.

From the above-given observations it can perhaps be inferred, that under the most favorable conditions, river water tends to a certain degree to purify itself of infective and other bacteria introduced. Yet the evidence thereby afforded does not seem strong enough to wholly justify such a conclusion. So long as fresh contaminations are constantly entering, the purificative tendency is virtually inoperative. Successive pollutions cause river water to become inferior in quality, as it is tested further down stream, and until after any considerable pollutions have for some distance ceased to enter. The liability to error, owing to unrecognized (and not easily appreciable) contamination of the waters, lessens the value of any tests made with our rivers. Hence, for the purpose of definitively resolving a portion at least of the problem, I have had recourse to a series of biological analyses of the Croton water in different parts of its flow through the magnificent aqueduct which for nearly half a century has so well served this city.* By reason of its superficial passage and of the configuration of the country, the old Croton aqueduct follows a more devious course than the new one. Therefore, and because of the thorough aërification, the old aqueduct (although dark throughout) is (for our purpose) much like an ideal stream, and is admirably adapted for testing the question at issue. The samples were collected at such intervals as corresponded with the flow of the current, which averaged a rate of a little more than 2½ miles an hour. Plates were prepared from the water as soon as it had been taken by means of the usual sterilized bottles.

Water of Old Croton Aqueduct.	Miles from Central Park.	Bacteria per Cubic Centimeter.				
		Dec. 25th, 1889, clear, 39° Fahr.	Feb. 27th, 1890, clear, 37° Fahr.	Apl. 3d, 1890, drizzly, 40° Fahr.	Sep. 30th, 1890, clear, 60° Fahr.	Oct. 11th, 1890, some hours after rain, 58° Fahr.
Sleepy Hollow, Tarrytown	27	....	....	420	372	....
Dobbs Ferry	22	....	453	....	....	....
Yonkers	17	....	283	....	....	....
Van Cortlandt	12	....	292	....	207	405
Bronx inflow, adding $\frac{1}{12}$ or less to volume of stream	....	....	[227]	....	....	....
High Bridge	6	347	266	413	240	377
Central Park (inlet to reservoir)	0	285	175	407	199	302
West side, hydrant	....	229	137	394	215	248
New aqueduct (slight temporary flow)	....	....	....	....	183	....
Surface of reservoir	....	....	....	....	72	143
1 foot from bottom of reservoir [35 feet deep]	....	....	....	....	487±	†
3½ feet " " " " "	....	....	....	....	368±	†

* I wish to indicate my appreciation of the courtesy of the Chief Engineer and his assistants.

† Hydrophore worked defectively, and, that day, the level of the reservoir water was 7 feet lower.

These results must be interpreted as indicating, that under the best sanitary conditions, the number of germs of bacteria present in a flowing water usually tends to become less after a course of a few miles, provided that no new ones have taken the place of those that have lost their vitality. After a single pollution by sewage-matter, introducing bacteria of various kinds, the bacterial contents of a given volume of a flowing water tend to gradually lessen in number. So, the question arises: How is this decrease produced? As factors possibly acting to bring about this result we may consider—dilution, sedimentation (subsidence), concussion, chemical influences (including oxidation), light, heat or cold, and the previously mentioned and admitted antagonistic action of other micro-organisms.

Dilution of the water in which they are living does not kill bacteria; and the fewer existing in a given water, the longer can any harmful ones present probably resist the antagonistic activity of the others. Dilution by a better water lessens, of course, the number previously existing in a given volume. Inasmuch as the little that is known on the subject leads us to infer, that of disease-producing kinds, a considerable number of individual bacteria must reach the vulnerable part of the invaded animal organism before they affect the health, if they do so at all; we may believe that a lessening of the number of harmful bacteria by means of dilution renders water less unfit for drinking, yet does not make it absolutely wholesome, even though causing it to appear relatively so. In the Niagara River, for instance, this element is very important. Having there several times been thwarted by rains and by other causes when starting out to analyze the waters, I received and examined a series of carefully expressed samples which, if they had yielded the same results to examination begun on the river bank immediately after they were removed from the river, would have allowed the inference that the river-water, contaminated by the sewage of Buffalo, became biologically as well as chemically much purer at Tonawanda, 11 miles lower down towards the cataract. Unfortunately the complete immediate examination could not be made. There, as in most rivers, the purification is in great part effected by dilution. In the river water above the falls very many hundred bacteria were found after a rainfall, which there, as in other places, can by surface washing bring in noxious elements.*

* Fluegge (*Hygiene*, 1889, 193) states that *bacillus Typhoid* has been isolated from earth of a field with which typhoid dejecta had "not long before" been mixed. We know that these and other bacteria can, under certain circumstances, live for months in dejecta.

See Grancher et Deschamps: *Archives de médicine* exp., 1889, I, 33.

Uffelmann: *Centralblatt für Bakteriologie*, etc., V, No. 15.

From various experiments* it is known that particles settling in water carry down a notable proportion of the bacteria present. The chemical agents which are at times employed, by uniting with the organic matter present, effect much more than the merely mechanically-acting, weighty particles. Like several other investigators, I have at times during the last two years endeavored to determine whether, in vessels of clear water from 10 to 20 inches deep (also twice in tanks 10 feet deep), bacteria settled to the bottom. The results have been neither uniform nor decisive, yet they seemed to manifest in general a slight tendency to subsidence. In laboratory tests the problem is rendered complex by the jarring of the building, the amount of air and light present, the variations of temperature, and other artificial influences unlike those operative in large bodies of water. The few observations made to test lakes, as by Fol and Dunant at Geneva Lake, Cramer at Zurich Lake, and Prausnitz at Starnberger Lake, do not indicate any great degree of subsidence. Of large bodies of water I have found:

August 28th, 1890:	Bacteria in 1 c.c.
Saratoga Lake, central part, surface	56
" " " " 13 feet down	54
" " 1 foot above bottom, 32 feet deep	163

The few tests here given of the water in the Central Park reservoir, permit the inference that there is there some subsidence of bacteria. Not to consider the larger number found at the bottom (as in only one instance did the apparatus work perfectly), there were considerably fewer on the surface of the middle of this large body of water, than entered through the aqueduct.

Very interesting in this regard are the results attained by G. Frank,† who found that the hundreds of thousands of bacteria regularly detected in the Spree River water, after it had received the sewage of Berlin, continued undiminished till after this foul water had passed into the Havel—a river that then for some miles flowed sluggishly through a series of broad expansions. After a course there of not much over 8 miles, it was usually found that the water taken lower down (from Sacrow) had only a few thousand germs. As this dimunition was, for chemical reasons, not to be explained by assuming an inflow of ground-water, it could be attributed to nothing but a subsidence of the

* Kruger: *Zeitschrift für Hygiene*, viii, 109.

† *Zeitschrift für Hygiene*, iii, 355.

micro-organisms in the lake-like widenings of the slow river, perhaps influenced by the abundant organic particles present. The government health office,* testing similarly the city sewage poured over a large area at the experimental station, found a marked diminution of the bacteria present. There many settled in the still water before it flowed over into the Rummelsburg Lake.

Concussion and movement of the water, I have not found to be followed by any considerable and immediate lessening of the number of bacteria, even in waterfalls† or where powerful pumps force it under great pressure. That harmful bacteria present can, notwithstanding vigorous concussion, produce fatal infection, is obvious from the causation of an outbreak of Asiatic cholera at Southampton, in 1866, resulting in 107 deaths. It was traced by Parkes to the dispersion of infected sewage through the air, by the unusual method of the bursting of many bubbles after the fluid had been churned up by powerful pumping, and in a frothy condition driven along an open channel.‡

That sunlight, as also diffused light, exercises an inhibitory influence upon the vitality of micro-organisms, has been a somewhat prevalent belief since the first report of Downes and Blunt,‖ which incited Tyndall§ and various following investigators. Raum¶ gives a list of many of these. A few, like Engelmann,** state their views that this influence does not arrest microbial growth and movement. The majority, like Janowski,†† consider that light, even in a diffused form, restricts the development and activity of bacteria. In deep waters this factor is of little consequence.

The even temperatures maintained in great bodies of water during the warmer portions of the year, are favorable to bacterial life. The combination of moisture and great warmth, as in the Delta of the Ganges, is considered a potent factor in maintaining the germs of cholera so constantly vigorous that there the disease is always endemic. Cold does not destroy all bacteria, although a certain number succumb to extreme

* Jurisch, Berlin, 1890, page 79.

† Schmelck (*Centralbl. für Bakt. und Paras.*, July, 1890, page 102), testing Scandinavian waters, found many bacteria in the ice formed from the spray of a waterfall. Here oxygenation, cold, light and the effects of concussion had all been operative.

‡ Frankland: Proceedings of the Royal Society of London, xxxv, 542.

‖ *Ibid*, xxvi.

§ *Ibid*, xxviii.

¶ *Zeitschrift für Hygiene*, vi, 313.

** Pflüger's Archiv, Bd., xlii.

†† *Centralblatt für Bakteriologie und Parasitenkunde*, August 1st, 1890.

cold. Congelation of the water in which they are living seems relatively favorable to a portion of the pernicious microbes present.* In many serious epidemics it has been observed that in ice and snow the infection of typhoid was kept active for months.

Some chemical waste from manufacturing establishments has a destructive effect upon these low organisms; but such vague and irregular means can itself only be called a pollution of the streams, and is highly undesirable. The typhoid fever epidemic of 1889, at Wilkesbarre, Pa., caused it to appear that the bacilli of that disease were probably unaffected by the commingling of coal-mine water (containing free sulphuric acid and ferric sulphate) with the Susquehanna River water, before this was taken by the water-works of the city.† When intelligently employed in suitable proportions, chemicals render foul water much purer. As a conspicuous instance of this I need only mention the city arrangements at Wiesbaden, by which the sewage is treated with quicklime. It thus becomes odorless fertilizer, and clear water flowing toward the Rhine. Dr. A. Pfeiffer,‡ unlike Fraenkel and others, asserts that, even after this thorough treatment of the sewage, from one-fourth to one-third of the bacterial germs remain alive in the water! If this be so, no acids or bases present in ordinary water are of any disinfectant value. Certainly the small amount of carbonic acid found in streams can devitalize no bacteria. Hochstetter|| and Fraenkel§ found that by the action of this agent only a few varieties were markedly affected, and that nearly all the harmful ones could live in carbonated waters for days. My own observations have been to the same effect.¶

The presence of a small quantity of mineral salts, as in the various mineral waters, has no notable influence upon the number of bacteria present. In all kinds of bottled waters from all parts of the globe living bacteria may be found, unless these waters have passed through a sterilizing process. Of the numerous waters flowing from the well-known springs in the Saratoga Valley, I have found that some were wholly sterile, while neighboring ones of like saline ingredients had hundreds

* Prudden: *Med. Record*, March 26, 1887. Bordoni-Uffreduzzi: *Centralbl. für Bakt.*, 1887. Fränkel: *Zeitchr. für Hygiene*, i, 2, 302.

† Breneman, *Jour. of the Am. Chem. Soc.*, xii, No. 1.

‡ Deutsche *Vierteljahrschrift für offentliche Gesundheitspflege*, xx, 55.

|| Arbeiten aus dem königlichen Gesundheitsamte, Band ii.

§ *Zeitschrift für Hygiene*, v, 333.

¶ *New York Medical Record*, xxvii, 680.

of living bacteria in each cubic centimeter, the determinations being made immediately after the water to be tested had issued from the ground.

Oxygen is everywhere present in the atmosphere in such abundance that, even in city streets, its proportion does not fluctuate more than ½ of 1 per cent. from the normal 78.3 per cent. contained in the purest air. Of this atmospheric air, somewhat less than 2 per cent. of the volume of a mass of water is taken by the water. This fact is the foundation for a satisfactory explanation of a great part of the actual lessening of the number of bacteria in a flowing stream. They may be assumed to perish, in the active exercise of their function of causing the organic matter to oxidize. When this impurity is in the form of the organic matter occurring in sewage, the process of oxidation is a much more active one than with the *humin* substances found more prominent in purer river waters. It can hardly be claimed that ozone is ever present in these waters in sufficient quantity* to act as a disinfectant. The same may be said of peroxide of hydrogen which, in the laboratory, as we may believe from the experiments of Altehöfer† and others, destroys *B. typhoid* and all other bacteria exposed for twenty-four hours to a 1.1000 solution of this in water.

We lack more precise knowledge than has been indicated by the references already made in this paper, concerning the antagonistic action of the various putrefactive and other bacteria upon the pernicious varieties. All that can be said is, that at least some of the various disease-producing kinds perish, or fail to increase, when the ordinarily-occurring varieties are abundantly present. Yet some harmful species may thrive, despite the presence and activity of common bacteria which suppress the less hardy of the harmful ones.

Summary and Corollaries.—While our knowledge of the causation and intimate processes of disease is at best very limited, and while telluric and other conditions exercise, upon our states of health and illness, influences not as yet comprehended, recent progress in biological science has caused us to know more and more about the origin and extension of various infectious disorders. In view of bacteriological explanations, we cannot doubt the potency of polluted water in inducing the

* Kowalkowsky, *Zeitschrift für Hygiene*, ix, 1, page 89.

† Altehöfer: *Centralblatt für Bakteriologie und Parasitenkunde*, July 25th, 1890, page 136.—Van Hettinga Tromp: Wasserstoffsuperoxide ter Desinfectie van Drinkwater, 1887.—Uffelmann: Jahresbericht, 1888, 47.

diffusion of some infections, and notably of typhoid fever. Like other harmful germs, the characteristic bacilli of this disease can live for days in water whose gross appearance is that of purity, and in which only the biologist can detect the impurity, although the other micro-organisms, such as are nearly always to be found in natural waters, tend to destroy the pernicious varieties.

There exists in all streams a capacity for at least partial self-purification after sewage or other pollution has entered. Biologically, this is manifested by a lessening of the number of bacteria present after several miles of flow, in case no fresh accession of inferior water occur. The pernicious varieties probably lose their harmful character, or when not excessively abundant are so diffused throughout as to be virtually harmless. Dilution seems the main factor in inducing this improvement, but oxidizing processes are of considerable importance in purifying waters. In rivers with very slow current, or in lakes, probably some bacteria settle. They unquestionably do so when the state of the water is such as to induce sedimentation. The application of this principle has produced beneficial results in the water systems of certain cities. "Antagonisms" among bacteria, shorten the life of disease-producing germs in waters where other (presumably harmless) kinds abound.

The excellent water supplied to New York is somewhat improved by the long flow through its aqueduct; yet too great care cannot be taken to keep the Croton watershed as free as possible from all habitations and industries. Only by vigilant and intelligent efforts can lasting and constant purity of the supply be maintained. Especially on summer days and during the time of high dry winds would it be advisable to more assiduously moisten the dusty and much frequented walks and roads about the Central Park Reservoir, as the deposit of much undesirable dust and accompanying bacteria in the water (shortly before its distribution throughout the city) could thereby be prevented.*

It is more economical and much safer to prevent contamination, than it is to use filters when the water has become dangerous. Large filters, when very carefully managed, effect a great improvement in

* When moistened, bacteria and the dust which is the usual means of carrying them through the air, remain upon the ground where they may have fallen. Unclean dust can be carried very far; but I will here only intimate that the excessive filth of our streets will be sufficiently remedied only when our greater and lesser lawgivers are made to realize the importance of cleanliness in every sense of the ill-understood word. Unclean streets and dwellings among the poor can cause disease among the opulent. The filthiness of individuals can endanger the health of the many.

inferior waters;* but they do not prevent all disease germs from passing through.†

It would be a most prudential act for the State to restrict the present devastation of its fine woodlands, and we should encourage the planting of at least one tree for every one hewn down. Forests afford a very valuable means of water-storage at the fountain-heads of our streams, and aid greatly to preserve the desired constancy of flow.

Inasmuch as impure water probably causes disease oftener than we can demonstrate, and as there is, unfortunately, an immense body of irrefutable proof of its frequent harmfulness, all suspected water—and this especially at time of an epidemic—should, like all other foods, be cooked. Concerning such liquid foods as water and milk, it may be said that a very brief boiling,‡ makes them free from the infective property which they in an uncooked state might possess.

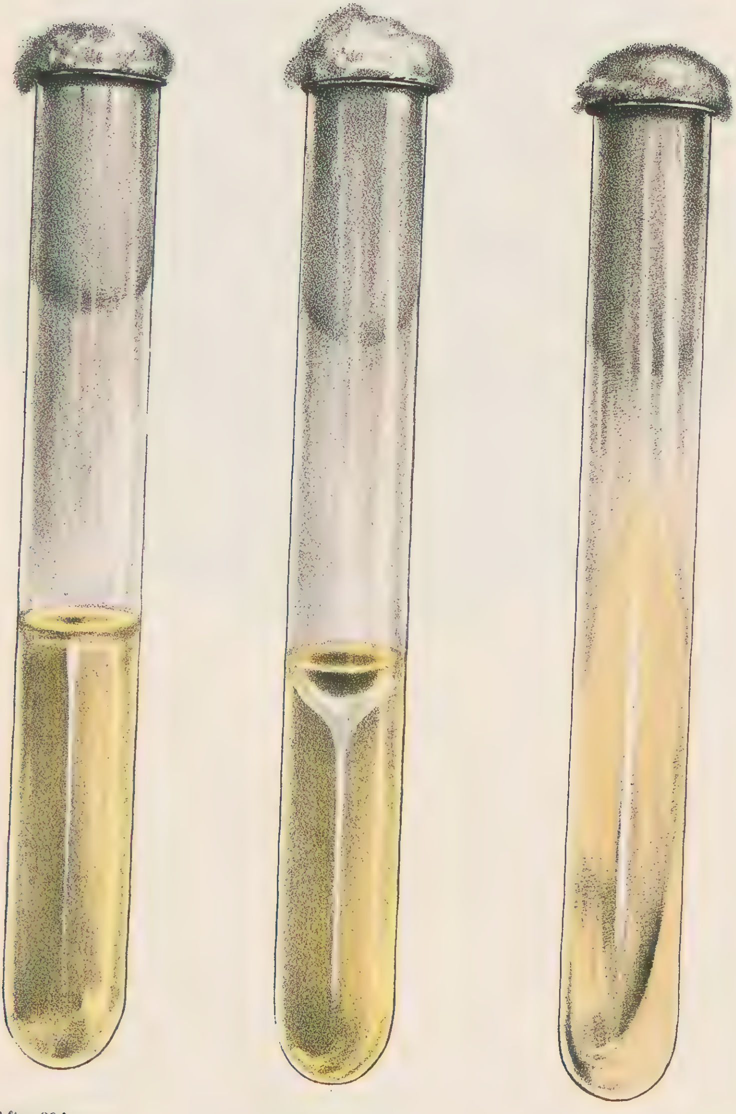
APPENDIX I.

Into test-tubes, such as are shown on Plate IV, we place a very nutritious bouillon rendered solid by the addition of 10 per cent. of gelatine and then steamed long enough to kill any germs which might be living in it. This becomes fluid as the temperature rises above 73 degrees Fahr. If to it in this softened state a few drops of average water be added and the mingled contents of the tube be poured into a shallow glass dish, the mass solidifies after a little while unless kept warm. The individual living bacteria which were in the added water are thus distributed singly throughout the even layer of the solidified nutrient gelatine, and in a few days each of these micro-organisms (perhaps less even than $\frac{1}{25000}$ inch in size, and usually not over $\frac{1}{5000}$ inch in length), has multiplied so enormously that we see in it, and upon the surface, spots varying in size from that of a pin-point, or smaller, to even that of a coin, and composed of many thousands or of millions of individuals. (See Plate V.) These are called "colonies." Their appearance varies greatly, and thereby in part we recognize different species. To study these further and distinguish species, we take a piece of platinum wire 2 inches long and fixed in the end of a glass rod, the whole having been passed through a flame to devitalize anything that might be upon it. We lightly touch the tip of the wire to one of these colonies and then pass the tip over the surface of (or into) various "culture-media" (such as potato, agar, gelatine, etc.), contained in test-tubes and which

* Currier : *Medical News*, April 27th, 1889.

† Fraenkel : *Deutsche Medicinische Wochenschrift*, December 12th, 1889, pages 1023, 1025.

‡ *N. Y. Medical Record*, June 14th, 1890 ; *N. Y. Medical Journal*, June 21st, 1890.



After 30 hours

After 100 hours

Koch's Cholera Spirilli in gelatine.

Oct. 29th, 1890.
C. G. C.

Typhoid Bacilli
Third day of
growth on Agar.

Oct. 29th, 1890.
C. G. C.

Croton water $\frac{1}{5}$ C. C. added to gelatine, and seen on black background Natural size, third day.

Water Bacteria from one of the constantly occurring, whitish-buff, liquefying colonies, colored with methylene-blue and magnified more than 2250 times.
(Zeiss' "Homogene Immersion", 2.0 M. M. aperture, 130 and ocular No. 18.)

have previously been sterilized by moist heat. In a few days the different varieties of bacteria have caused peculiar and distinctive growths to appear. If a minute portion of one of these is spread on glass and viewed through a high power of the microscope, it will be seen that the growths are composed of very many minute bodies which are bacteria. Some bacteria—as, *e. g.*, the variety characteristic of consumption (*Bacillus tuberculosis*) and those which thrive only in the absence of oxygen—have to be studied in other ways, yet this sketch indicates the general principles of the Koch method of determining the number and varieties of water-bacteria present in a given sample.

APPENDIX II.

THE EFFICACY OF FILTERS AND OF OTHER MEANS EMPLOYED TO PURIFY DRINKING-WATER.

*A Bacteriological Study.**

By CHARLES G. CURRIER, M.D.

Water, even after having been exposed to various chances of contamination, is very generally drunk as it is received from lakes or rivers, wells or springs, tanks or hydrants; and, despite the most disinterested warnings, people are not ready enough to believe that clear, sparkling water may at times be the most harmful of beverages; that it can carry with it, and introduce into the systems of a portion at least of those who drink it, the immediate causes of various impairments of health. Polluted water may be agreeable to the taste and have no visible sediment, yet cause many deaths. Such water the unskilled are slow to suspect, and but for the advance in sanitary science, and the warnings conveyed by those familiar with hygienic studies, pure supplies of drinking-water in cities would be much more of a rarity than they are.

At the Hygienic Congress in Vienna, in 1787, M. Brouardel stated that he knew of over sixty epidemics of typhoid fever which had been induced by the drinking of infected water. From typhoid fever thousands of deaths occur every year; and, although scientific physicians are constantly urging these facts, it seems to be necessary that the danger present itself in the form of an epidemic before the people fully realize the immense harm which may result from impure drinking-water. The epidemic which ravaged Plymouth, in Pennsylvania, four years ago, attracted great attention at the time, but the history of several similar

* Read before the Section on Public Health of the New York Academy of Medicine, April 5th, 1889.

Condensed from *The Medical News*, April 20th and 27th, 1889, where some of the bibliography can be found.

"visitations" since then, would indicate that the full value of this severe lesson has not been properly appreciated.

Water may be very highly colored, and yet, if freshly collected near its source, show no very large number of bacteria. Such is the case with the best of the peaty "juniper" water which I have examined in various parts of the Dismal Swamp of Carolina and Virginia. Although having a large proportion of organic matter, this water is reputed eminently wholesome, and an inquiry among a portion of those drinking this exclusively, appears to show an unusual degree of immunity from the manifestations of diseases which might be attributed to the effects of improper drinking-water. If harmful bacteria be introduced into it, such water favors their increase, while they would not be so apt to multiply in a very pure water having much less organic matter. Despite the good reputation which this water has had, and its wholesomeness near Lake Drummond, one who has seen the whole length of the canal down to the lower end, from which the supply for vessels is taken, can realize that the water may undergo considerable contamination before it reaches that part. I am sure that the present use (in our navy) of distilled water, kept in proper receptacles, is safer than the employment of the swamp water. On the other hand, the turbidity which is common at this season of the year in the streams furnishing the water supply of many of our cities, is almost always accompanied by a large number of bacteria. The melting snow and the rain, which wash into the streams an increased amount of organic matter, introduce with it other germs (perhaps pernicious), and bring more nutriment than usual to the micro-organisms already in the water.

It is believed that, like most of the varieties of bacteria found in water, the still larger forms of animal and vegetable life, ordinarily existing in lakes and rivers, are not prejudicial to health. It is through the products of the decomposition of many of these, when their life has ceased, that they may become harmful.

Chemistry has long furnished a means of recognizing polluted water, even when it yielded no sediment visible to the unaided eye; and the presence of considerable quantities of chlorides, nitrates and ammonias, determined by the chemical tests, has shown that many a water had more organic impurity than was considered desirable; and, when far below the accepted standard in this respect, such a water is justly condemned. Yet it seems as though enough of the infective element of cholera or typhoid to diffuse an epidemic throughout a community can be added to a drinking-water, and not be detectable by chemical tests. A perusal of the very complete and instructive paper by Professor J. W. Mallet (in the report of the National Board of Health for 1882) shows how widely such determinations may vary, and how unreliable chemical standards may be. We are thereby made to recognize that a close acquaintance with the entire watershed, is of greater value than a mere chemical determination.

The known disease-producing bacteria, however, do not appear to increase in water in which there is not more organic matter than the proportion that chemists of constant and large experience regard as permissible in waters which they pronounce to be of fair quality, although these harmful bacteria, if once introduced there, may long retain their vitality and remain dangerous. In my tests, when I prepared an artificial water, I added the germs directly from a pure culture, unlike Bolton, and like Wolffhügel and Riedel (Arb. aus d. Gesundheitsamte, 1886, i. p. 455), with whose results, however, I cannot so well agree as I can with those of Bolton (Ztsch. f. Hygiene, 1886, i. p. 76). I have in but two out of many trials, with disease-producing species, found typhoid bacilli to increase in sterile pure water, and then only to the extent of 30 per cent. In the Croton when it was sterilized, I have been able to keep typhoid bacilli alive for only two weeks, and usually not over eight or nine days. I have observed that the greater the variation of temperature it was exposed to, the shorter time did this micro-organism live in water.

Since, as yet, chemistry, when called upon to aid in solving the question of the purity of a water, can at its best only approximately estimate the amount of organic matter present and its state of oxidation, while it fails to inform us whether infective matter be present or not in a given water, it has been hoped that a sure means of recognizing whether a water be in any degree infected was reached, when Koch introduced the bacteriological test. This test, while very definite and conclusive under favorable conditions, has thus far been able to decide absolutely, in only a small portion of cases of disease apparently coming from the use of drinking-water. Yet in those cases where the bacteria characteristic of distinct disease have been detected in the suspected water, the isolation, culture and identification of the disease-producing species, furnish a convincing proof of the great value of the method.

The method employed is a simple one. Usually 1 cubic centimeter of the water to be tested is added to 10 cubic centimeters of nutrient jelly, made by solidifying very nutritious beef tea by the incorporation of one-tenth its weight of gelatine. Everything being done with rigid precautions, the water to be tested is added to the nutrient jelly, which has been softened by being warmed to a little more than 30 degrees centigrade. This is then quickly mixed and poured upon a cooled glass plate, where the fluidified gelatine soon becomes quite solid. Then the germs in the water, being scattered evenly throughout the mass, exercise their functions of rapidly multiplying at the room temperature; and, in the nutritious medium, the minute microscopic individual has perhaps by the third day become a dot as large as a pin-point, or much larger, containing thousands or millions of newly-formed bacteria. These are called "colonies," and vary considerably in appearance, as will be seen by comparing the plates made with various waters. With a glass ruled into centimeter squares the number can be counted or estimated. If a large number of thousands be present, as in waters artificially prepared for tests and in sewage contamination of water, the only way to arrive at an accurate estimate is to employ in the eye-piece of a microscope a micrometer square. After determining the number we isolate and identify the species as in general bacteriological study.

There are many features of the subject which must be omitted in a paper of this scope, for they may not interest all, and I will not linger over the still unsettled question as to the absolute value of mere numbers of ordinary water bacteria in determining the sanitary merits of water.* It is, however, admitted that the fewer the varieties present, the less is the likelihood of sources of contamination affecting the water. In examining a considerable number of samples of water from various sources, I have observed that the less chance of contamination there was, the fewer bacteria have I found in the waters. Thus, fine mountain lakes and springs have never in my experience, unless under very un-

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* Gärtner: Correspondenz Bl. d. allg. ärzt. Ver. von Thüringen, 1888; Nos. 2 and 3. Centralbl. f. Bakt. und Par., iii, 5, p. 161 *et seq.*

Wolffhügel: Arbeiten aus dem Gesundheitsamte, Band i., iii, 5 Heft (1885), p. 546.

Plagge und Proskauer, Ztschr. f. Hygiene, 1887, pp. 470 and 486.

favorable conditions, shown as many as one hundred bacteria in each cubic centimeter, while the same quantity of water, from a river draining thickly peopled valleys, may show more than fifty times as many. While it offers less striking extreme differences than I have seen in the Hudson Valley and elsewhere, the Passaic water-shed may be briefly instanced as illustrating what I have just said. I give it because it is the smallest one near us offering every phase of importance in this connection, and because the subject of a supply to come to New York from that source, has been seriously considered. The best of the upper lakes of this system showed on a pleasant day of the past winter, only fifty-seven germs developing in the nutrient gelatine; the Pequannock and other tributaries into which these lakes flow showed, in the samples collected as nearly at the same time as possible, over three hundred and fifty germs, which number increased as the water was taken further down stream; while at the Passaic Falls, in Paterson, over a thousand were detected in each cubic centimeter. Water from a hydrant in Newark, at the same time, showed nearly four thousand germs of bacteria in each cubic centimeter. The Newark water supply is at present derived from the Passaic, some miles below the place where sewage from Paterson is discharged into the river.

As in chemical, so in bacteriological water examinations, those who have had the broadest experience and who are most careful are best in a position to pronounce an opinion. Apart from any personal equation, there are still limitations to the entire comprehensiveness of the method. I may mention that bacteria are recognized as present in the human body and in its products and changed tissues, which bacteria are never found to live on the gelatine or other water plates. Then, too, a water may be submitted for examination when all the obvious infection has disappeared, or has become exceedingly diluted, and hence a most painstaking test, then fails to reveal the presence of the characteristic microorganism. The period of incubation, after the infection and before the symptoms are recognized, may in Asiatic cholera occupy the greater part of a week, and in typhoid often lasts for two weeks or more, so that all traces of the harmful bacteria may have left the water before it is suspected. By reason, also, of its likeness to various harmless species, and its tendency to be overwhelmed by other more rapidly developing forms, the "colony" of the disease-producing species may be hard to identify. In this respect typhoid is decidedly more difficult than cholera to recognize in ordinary water.

For those who believe that bacteria of certain kinds living in water, and with this introduced into the alimentary canal, can in many cases induce disease; this test, being so precise and delicate as it is, must appear the best way of determining whether the filters and other means in common use are efficient, or otherwise, in removing the dangerous elements from impure water passed through them—in short, whether they act as "disinfectants" of the water.

As various other agencies are used in conjunction with, or as supplementary to, filtration, it is proper that I here indicate how far they serve to purify drinking-water. One of the most prevalent means directly resorted to for this ostensible purpose, is the admixture of wine (usually red). Adding this to an equal amount of Croton water, I find that a varying proportion of the bacteria are killed, sometimes less than half, even after the mixture has stood for days. The spirituous alcoholic beverages (having from 45 to 68 per cent. of alcohol), mixed with Croton hydrant water in equal parts, cannot be depended upon to kill all the bacteria, especially when "earth" bacteria are present, and a small percentage of whisky (less than 20 per cent.) has very little effect in this direction. In malt liquors, as lager beer, the prolonged boiling in the brewer's kettle has destroyed the bacteria of the original water, even if they be of the most harmful and resistive species which we meet here. Various kinds, however, if present in vats, kegs and bottles, (because of imperfect cleansing), will live in beer. Almost all the artificial mineral waters that I have examined are made of unsterilized water. Pressure of carbonic acid gas, and contact with it for days, reduces greatly the number of bacteria in a mineral water, yet the typhoid bacillus and others will live for days in seltzer water and similar waters. In New York I have found many bacteria in the few carbonated beverages that I have examined. Peroxide of hydrogen, one part to one thousand of water containing harmful or harmless bacteria, destroys these in twenty-four hours. Yet this is an unstable compound which will not gain much usage.

Of the various acids which it is occasionally safe to employ, chemically pure hydrochloric acid must be used in the strength of at least one-half of one per cent. to destroy all the germs in Croton water to which *B. subtilis*, *B. typhoid* and other bacteria have been added; and may fail to sterilize the water even after hours of standing thus acidulated. Sulphuric acid is more than twice as potent, and usually in the strength of one part to five hundred of water, will render this free from living germs. Sometimes, however, it has to be used still stronger, as it is in a certain extensively advertised nostrum, in which, under a fanciful name, it plays the principal part. Alum, lime and the other chemicals which, by inducing sedimentation of organic and mineral constituents, carry down many of the bacteria in water, do not (as is often believed) insure the annihilation and destruction of organisms present. It is the mechanical action of the film, which the presence of a minute amount of these causes to settle sooner than would otherwise occur upon sand in certain large sand filters, which insures their excellence, and the scarcity of bacteria must here not be attributed to a coarse chemical action. When chemicals are added in sufficient strength to destroy speedily all the bacteria which may be present, the water thus treated cannot be recommended as a beverage.

With the imperfection of all other methods, we have in prolonged boiling a sure disinfectant of any water. I have usually found that maintaining a water at the boiling point for even less than fifteen minutes, sufficed to prevent any of its germs from developing in gelatine, and this even with bad waters from sewage-infected rivers. The process of distillation likewise sterilizes water.

The germs of cholera and typhoid are very sensitive to heat, and boiling heat kills them at once.

That freezing temperatures destroy only a certain proportion of the bacteria which exist in the water from which the ice we use is formed, has been established by, I think, repeated observations. I will simply warn against putting ordinary ice into water which we are to drink, as many kinds of bacteria may be thereby introduced. Ice made of distilled or boiled water is wholesome.

The mechanical separation of impurities is the principal action in all filters, whatever their composition. The amount of oxidation produced by the passage of considerable quantities of water through inconsiderable masses of charcoal, sand or anything else, seems never sufficient to chemically purify an infected water, although the Berlin system of filtration, by large beds of sand skillfully managed, effects a notable improvement in this respect. In some cases the nitrifying bacteria present appear to produce a noteworthy improvement. This element will be spoken of later on.

Almost all tissues tend to separate visible particles from water which is turbid, or in which a deposit settles. The fact that such matter is retained from the water passed through filters, appeals very strongly to most persons; and the general assumption that such visible matter is dangerous, and that its removal insures the purification of water, seems to explain the extensive use of filters. They are all composed of felt-like matter (filtrum), or of any tissue or substance so woven, composed or arranged, as by its structure to more or less completely arrest the passage of sediment and the floating particles existing in varying amounts in nearly all natural waters. The filters in domestic use may be arranged in two classes. In one class the water runs or is poured into a tank, or other receiver, over or beside some filtering medium, through which the flow is into a receptacle, and from this the water is taken as needed, or is stored as fit for drinking. Those of the second variety are designed to connect with the faucets, and to strain from the water such impurities as it brings through the hydrant.

One of the most widely used varieties is a portable one, which renders water clearer and more agreeable to the eye. It is composed of a cylinder of pressed carbon, 3 inches or less in diameter, and having nearly the same depth, which has from its interior a tube passing through the bottom of the funnel in which it rests, thus requiring all the water passing out of the bottom of the funnel to go first through the mass of carbon. The flow is very sluggish unless use be made of pressure or suction, as, for example, by lengthening the tube taking water out of the filter. This, by hastening the action, impairs the effectiveness so far as purification of the water is concerned. After this has been used for a few days, the retardation is very marked, due to the clogging of the filter by the various matters which form the sediment of the unfiltered water. This necessitates frequent cleansing.

Taking a freshly sterilized carbon filter of this sort and pouring into the funnel Croton water just drawn after considerable has run from the faucet, and then collecting in sterilized test-tubes the first flow from the filter, adding of this (as already explained) one cubic centimeter to ten parts of softened nutrient gelatine, the mingled gelatine and water being poured upon a cool plate, it is seen that, before three days have passed, several colonies have developed. Comparing the number of these with that found from the original Croton water plated just after being drawn, we find that at least from 5 to 8 per cent. of the bacteria pass through the filter and develop. The percentage rises as more and more water flows through. From fourteen trials made with simple Croton water, I found that through a carbon filter, freshly sterilized and the introduction of germs from the air and other sources of contamination being guarded against, the first flow showed only a small percentage of the bacteria found in the original water used. Then I continued the use of the same filter without resterilizing it, and endeavored in every way to have the conditions under which it was tested as much as possible like those which would exist in domestic use, and the supply of water in the funnel was allowed to become exhausted at times, as usually during the night. In this filter thus used, the number of bacteria in the water passing through is, on the second day and thereafter, much larger than in the water taken after being poured into the funnel and before it has percolated through the carbon block. This excess, when large, seems to bear an inverse ratio to the volume of the flow.

It is a familiar fact that, if fresh hydrant water in a flask covered with cotton (to prevent the entrance of bacteria from the air) be allowed to stand for a day at the temperature of the laboratory, the original bacteria in the water may be found to have increased considerably. So, as a collateral test, after water had been poured into the filter and before it had passed through the carbon, I have taken some of this original water and allowed it to stand in test-tubes and flasks, both stoppered and open, by the side of the filter similarly protected from the entrance of germs from the air, and exposed to the same variations of temperature.

This water, examined at the same time with that coming out of the filter, showed that the bacteria appear to multiply much more rapidly in the substance of the filter than outside in separate flasks, kept at the varying temperature of the laboratory, as it then was. The water poured in rarely contained as many as 225 bacteria in each c.c., and yet in from one to three days from the time when the freshly sterilized filter had begun to be used, the water after passing through the carbon showed several thousand in every case, and at times more than 25 000 bacteria in each c.c.

All sorts of bacteria appeared to pass through, and not alone water species. The bacillus of typhoid fever will not only pass through, but in two of my trials I found that it had increased. For such special tests I used sterilized Croton water, into which bacteria were introduced from pure cultures. For artificial typhoid water, the bacillus of typhoid was added from agar and potato cultures. Harmful bacteria can pass through such filters, can possibly increase in them under certain favoring conditions, and from parallel tests, seem to retain their vitality longer when in the substance of the filter than when in a glass vessel beside it.

Clean sand fairly represents the granular masses of filtering material, and has all the advantages of powdered charcoal and magnesia as generally used for filtering considerable quantities of water, while it is more readily cleansed of the accumulated organic matter, and, unlike spongy iron, adds nothing objectionable. Unless, as in the case of the large Berlin filters and others acting similarly, rendered more effective by overlying silt and organic matter, beds of sand do not prevent the passage of large numbers of bacteria. I have found many bacteria in waters from various artesian wells coming from a deep stratum of sand, though the best ground-waters are very free from these. Through a thin sterilized layer, from 6 inches to 1 foot in depth, of the finest sand procurable from beaches, all the way from 40 per cent. to 95 per cent. of the bacteria in the original water pass, even when the level of the water is never more than 3 inches above the surface of the filtering mass. When a higher pressure is afforded by the water, very few of the bacteria are kept back.

As in nearly all other filters, so through a layer of sand, all kinds of bacteria, harmless or harmful, appear to easily pass. Here, too, they can multiply in the moist sand. Thus I have found the hydrant water, which entered the sand filter with 290 bacteria in each c.c., to come out through the filter (not freshly sterilized before using) with sixty and one hundred times as many as entered. In a gram of sand taken from a filtering bed, I have found more than 10 000 bacteria.

The combination of other substances with sand, as in numerous small and large filters, fails to improve the usefulness of either, except in so far as the elimination of sedimental and other coarser particles is concerned. Sponge is often employed for this purpose, as well as independently, yet it is incapable of separating bacteria from the water strained through it simply, or through sand or other substances used with it. When a large mass of fine sterilized sponge is closely packed, the first few ounces of hydrant water that pass through may have a very small percentage of bacteria, but the proportion soon increases; while if the sponge-mass be considerable and loosely packed, it may, even in the beginning and under exceedingly slight pressure of water, keep back no more than 15 per cent. of the bacteria of the original water. This freshly sterilized sponge can, at the end of the first day of ordinary use, cause the water then flowing through it to contain ten times as many bacteria as the Croton water poured in. The stronger the pressure, and the more rapid the flow, the lower is the ratio of excess due to increase in the filter over the quantity found in the unfiltered supply, which, of course, was here, as in all other tests, regularly plated at the same time with the filtered water. When the flow is sluggish, and when it stops entirely at times because of all the water supplied having passed through, the sponge substance favors the increase of the bacteria to a greater extent than is the case with sand. The sponge, within twenty-four hours after sterilization, may, under these conditions, cause the water first running through after the intermitting of the flow, to have five hundred times as many bacteria in each cubic centimeter as are found in the water supplied for filtration.

The only way really to cleanse such a filter, is to remove the sponge and boil it. Then the process repeats itself. In a few hours after unsterilized water moistens it, the mass of sponge is again teeming with bacteria. Sponge filters are, so far as I have seen, becoming less popular. It is easily recognized, even by an untrained observer, that the organic matter in sponge can undergo decomposition under the conditions obtaining in ordinary filters. Several of the large filter systems used in manufactories, hotels and other places where large amounts of strained water are used, employ sponge, and the filtered water abounds in bacteria. Filter paper, as used in laboratories, is useful in separating precipitates and sedimental particles from water, but at least from 50 to 70 per cent. of the bacteria in Croton hydrant water go through with the water filtered, even if the pressure be exceedingly slight. The paper which I employed in the trials was, of course, carefully selected, and the folding was cautiously done, so as to prevent any break in the substance. Only single sheets were tested.

"Prepared cotton," cleansed as for surgical dressings, and so made absorbent, removes considerably fewer of the impurities of the water than does the filter paper. Two-thirds of the bacteria pass through when the cotton is at its best, freshly sterilized and carefully packed. If enough be used, it will usually render the water clear; but, as it has been lauded as a filter, I ought to add the statement of my observation, that when left moistened with water, as in the intervals of filtering through it, the bacteria of the original water can multiply over one hundred and fifty times, and all kinds can pass through it.

Combinations of the various substances mentioned have hardly any enhanced merit as strainers, and, as far as the bacteria are concerned, the combination seems to add no safeguard. Sand with carbon (bone charcoal) and sponge or cotton, hold back at first a larger percentage than sand would by itself. Yet bacteria pass through in any case, and the increase afterward is greater than in simple sand. This I have seen in various filters.

In well-known establishments of New York, where immense quantities of artificial waters are prepared every week, all the water used in their preparation is supposed to flow through a layer of fine sand in the bottom of enormous vats, and from the receptacle into which it then flows, it passes through a layer of charcoal. These layers are each less than a foot in thickness, and water passes rapidly through. The sediment is thereby removed, but in the examinations which I have been enabled to make, I found that each cubic centimeter of the filtered water had over 2 000 bacteria on each of the plates made, while the Croton taken from the hydrant in the immediate neighborhood averaged never over one-eighth as many.

Asbestos of the best quality, new, freshly sterilized and tightly packed, I have found capable of holding back all bacteria when the pressure of the water was low, and the few that were forced through when the substance was defective, did not seem to multiply so rapidly as in other filter masses. While it, when of the best finish and most tightly compressed, deserves to rank next to the principle employed in porcelain filters, these latter are superior in that they can be regularly furnished of a uniform and definite quality which produces the best results, while it is difficult to keep the best asbestos boards up to their original standard of excellence; and if the surface be large enough to insure an abundant flow of water, flaws are liable to arise, and these let various bacteria through. With asbestos it is the fineness of the surface which the original water encounters that is important, more than the thickness of the layer.

Although wire cloth strains out the coarser particles, its structure does not cause the removal of any of the bacteria from water passing through. Still it has the positive merit of being easily cleansed, and can be heated in an oven or boiled to sterilize it. Furthermore, it does not furnish a filter mass for the bacteria to multiply in, although harmful bacteria can adhere to it, and become dangerous, if it be left uncleaned.

Closely woven cloth (such as thick, dense flannel), when only a slight pressure is exerted by the water, may stop 10 per cent. of the bacteria in the water poured upon it. It is easily cleansed and, if very often changed and boiled before using, serves excellently as a simple strainer, without the disadvantage in this respect of ordinary filters, in whose substance the increase of bacteria may be enormous.

Like porcelain, filters of porous stone (if of the best quality), prevent the passage of bacteria with the water filtered through them just after they have been sterilized. To test porous stone, I employed selected perfect specimens of a popular filter which very satisfactorily clears all turbidity from as bad a water as that of the Hudson River, at its worst. In these, the stone layer was cemented into a porcelain cylinder, and was about $\frac{3}{8}$ths of an inch in thickness. The pressure was never more than that of 10 or 11 inches of water, and, at the fastest, less than $\frac{3}{4}$ths of a liter passed through in an hour. As the sediment of the water settled upon the surface of the stone, the flow became much slower. During twenty-six trials of this kind of filter, it had previously been sterilized ten times by exposure to moist or dry heat, or to both, for several hours. In every one of these ten cases the various waters poured into the receptacle above the porous stone for the first time after sterilization, flowed through germ-free; that is, the stone was permeable for water, but at first allowed no bacteria to pass through, and the plates of gelatine developed not a single colony from the usual cubic centimeter of the filtered water. After some hours of use, a few bacteria had insinuated themselves into the stone or were drawn through with the water. Within twenty-four hours the water flowing through and collected in sterilized receptacles contained many bacteria, which numbered regularly from seven to fourteen times as many as were in the original hydrant water supplied during these trials. After several days, the number of bacteria had so multiplied in the stone, that the first water running through after the stone had remained for several hours without any flow through it, (as happens constantly over-night in domestic use), showed in each cubic centimeter of this filtered water over one hundred times as many as the average water poured in for filtration. To further test these filters, I have used artificial waters made by adding bacteria of all shapes and characters (from pure cultures) to Croton water sterilized by boiling. These various kinds can get through, but the disease-producing and spiral forms usually died out in large numbers before any could pass. From Croton water, the most marked by its predominance in the filtered product, was a short, mobile bacillus, which was unlike the two varieties first forced through the porcelain in my experiments.

Allied to the porous stone filters, are those of porous porcelain prepared in this country. Porcelain baked at the same low temperature as the porous cups used in electric batteries is, in its efficacy, very much like the stone just described. Under a low pressure, water passing through this substance during one or two days can become completely sterilized, which is a result superior to that got from the stone filters. Before much water has passed, the bacteria make their way through and multiply somewhat on the passage. This material, as I have thus far found it, of American manufacture, is therefore imperfect, yet it is superior to rebaked porcelain, in the single important respect that it is not brittle, while the rebaked porcelain cylinders of the Chamberland-Pasteur filters are quite fragile.

It has for some time been known that fluids can be rendered germ-free for laboratory use, by being passed through solidified plaster of paris (best prepared with incorporation of asbestos shreds). These filters, however, lack permanency, and cause the objectionable sulphate of lime to be present in the filtrate.

Recognizing the defects of other substances, Pasteur and Chamberland called attention to their filtering cylinders, in which the important element is unglazed, rebaked porcelain. Originally employed to facilitate "cold sterilization" of fluid culture media, the fact that water went through the porcelain without carrying any bacteria with it, has caused attempts to popularize its use. Inasmuch as some bacteriologists on both sides of the Atlantic had reported that this filter prevented the passage of bacteria, I was careful to use only selected cylinders without flaws, and did not omit any precaution to prevent the introduction of contaminations.

The most satisfactory way of using this for testing was to employ the single porcelain cylinder, within the usual casing, attached to a hydrant system and with a pressure of water varying from 6 to 15 pounds. Even with the highest New York hydrant pressure the flow is only drop by drop. It can be used to siphon water out of a jar, and in this way it works nearly as rapidly as when attached to the hydrant, in the basement of a house, in the center of this city. By a porcelain cross-tube sold in Paris, two or more cylinders can be siphoning at the same time into the same tube. To avoid risk of contamination, I used for siphoning a single cylinder, to which a bent glass tube was attached by a tightly fitting piece of rubber pipe, all parts having been sterilized, as well as the water by which the flow of the siphon was started. I got germ-free results regularly by this means in seven trials with two cylinders used separately; but, in order to insure this, all the precautions mentioned are necessary, as, in the water siphoned in domestic use of these cylinders, bacteria of various sorts are found, yet they are possibly contaminations due to the inherent defects of all such joints as are used. So I have devoted more time to testing these when directly connecting with the hydrant, as very slight precautions are needed, in their use with faucets, to eliminate all chances of contamination.

My first thirteen trials of this filter used in this way were under less satisfactory conditions than the fourteenth and those following, as the former were in a laboratory where the available water came under not much more than 20 feet pressure from a tank, and I was not able so well to control the constancy of this pressure as I was during the later trials. My first sixteen tests of various ones of these cylinders gave sterile water. Then, attached to a basement faucet, with a direct flow from the hydrant under a pressure never exceeding 15 pounds, (except that on Sunday nights it was for a few hours 3 pounds higher), the filter, after several days of intermitting use, gave over 3 500 bacteria in each cubic centimeter, and all the water examined (two samples per day) for four days, showed an increasing number of bacteria.

On the third and fourth days after the first passage of bacteria through the porcelain wall of the cylinder, the number in each cubic centimeter varied above and below 400 000. The filter was then sterilized by steaming for five hours, as was also done between the second and third series of tests. These tests bore out the results of the former observation.

That these results show that average specimens of this substance have the inherent defect of all filtering material, though in a much less degree than all others, seems to me unquestionable. That the bacteria did not get through owing to some defect in the particular filters which I used, is evident from the fact that the cylinders employed (and which were selected by me in Paris as perfect), through which the bacteria passed, are still free from any appearance of a flaw which could explain the passage of these micro-organisms. The same filter which (first of those used in my tests) allowed bacteria to pass through, has repeatedly filtered water free from all bacteria for a few days, after each of the several sterilizations which it has since undergone.*

In three following series of trials of this identical cylinder, bacteria have gone through its walls in from three to four days after each sterilization. They have also gone through a second perfect cylinder with which I experimented. That the bacteria were not introduced by careless manipulation is evident by reason of their number, and because of the fact that, after the filter was sterilized, they were found in each case at a particular phase of each series of tests with the intermittent pressure, which only for a few hours once a week was as high as 18 pounds, and was usually as low as 11. At the beginning of each series of tests the filter was sterilized.

The bacteria were not splashed in from the sink below, for, in the first place, all splashing failed to carry in any, as revealed by testing the water filtered after such experimental attempts to throw water in, and none had ever multiplied inside or even remained there during my first thirteen tests, when there was much splashing in the common sink. During my later trials there was no chance of such contamination.

To answer fully in advance any such objection, I will state that after I got the enormous number of over 400 000 in each c.c. flowing through the porcelain, and had sterilized the cylinder, water was allowed to flow

* My results have later been corroborated by experiments made in Koch's laboratory, in Berlin. Kubler, *Zeitschrift für Hygiene*, viii, 48 (1890).

through it and plated, but was sterile in that no bacterial colonies developed. Then, while the filter was in action, I introduced, with a sterile needle, (from below through the aperture into the inside of the cylinder), and, touching the needle to various parts of the surface, deposited over it peculiar bacteria from a pure culture, derived in the winter of 1888–89 from the water of one of the northern lakes, which I examined during my investigations as biologist for the Syracuse Water Commission. The colonies of this bacillus, when grown on gelatine plates, have a peculiar odor, a distinctive green color, and other characteristics which clearly differentiate them from any bacteria ever found in the Croton water. The water flowing out all the while, or rather dropping out, was, three minutes after the introduction of these, collected in sterilized test tubes, and was found to contain 175 000 of these peculiar bacilli in each c.c. After seventy five minutes there were only 14 bacilli in each c.c. of the water then flowing through the porcelain, and two hours later, and during the next day, there were no bacteria of any kind in the water, which again later in the series showed that the Croton bacteria had passed through with it. This proves that the increase in the number of bacteria was not after the water had passed through the substance of the filter.

These facts, together with the extreme fragility of this rebaked porcelain, and the exasperating slowness of the flow, which does not improve on long trial, have caused me to modify the recommendations which I gave among my colleagues and others after my first tests of these filters.

As regards rapidity of flow and non-fragility, a notable improvement over the cylinder form (which I have just spoken of) is afforded by a series of two or more flat plates of porcelain similarly prepared. In the Varrall-Brisse pattern these porcelain plates are backed by carbon plates of the same shape and size, and the filter yields sterile water for a long time under gentle pressure, although I do not consider the carbon an advantage. The further such filters vary from the simplest type, the greater is the likelihood of the introduction of contaminating bacteria into the filtered water.

Of the various forms of filters used upon faucets, I feel bound to warn against those rotating within an outer shell. Whether packed with charcoal, sand or any other material, and even if the water go through the filtering mass and not around it, the filter has the great drawback of various irregularities and depressions on the interior which retain organic matter, and allow bacteria, both harmful and harmless, to increase in it, and maintain their vitality for a longer time than in ordinary filters. This conclusion I am led to by the results of various experiments and observations. In a recent epidemic in a large New England city this form of filter appeared to play an active part in continuing the infection, for cultures, in every respect like those of the germs of typhoid fever, were derived from several of these suspected filters. I have found that the typhoid bacillus lives much longer in the sediment collected from filters than in pure water. At its best, this filter cannot remove the bacteria from water, and they multiply in the charcoal or sand so that, even after several minutes of washing out by the stream flowing from the hydrant, the water coming through this filter may show several times as many as are in the water directly from the hydrant. To avoid waste of time in repetition, I will refer to the facts observed with the sand filter, as the mechanical action of the filtering mass is identical in both.

The sand filter, for attaching to faucets, is perhaps the simplest and most popular used. It consists of a cylinder of like breadth and length, being not quite 3 inches long. It screws by either end upon ordinary faucets, and its interior is filled with crushed silica or fine sand, kept in place by wire gauze at either end. I have adapted several much larger without securing more satisfactory results. Taking a new one, sterilized throughout, allowing a fair stream of water to flow through it when attached to a faucet, and at the same time taking water directly from the same supply-pipe from the hydrant by means of another faucet by its side, and under the same conditions of pressure and outlet (except that there is no filter upon the second faucet), the water is seen to flow in a free stream nearly as large as from the unobstructed faucet, while the Pasteur filter attached to the same supply-pipe, and with the same pressure, allows the water to come at the rate of only a few drops each minute. Even with a gentle stream through the freshly sterilized sand filter, very few of the bacteria are arrested. With very fine sand in a cylinder holding three times as much as the ordinary one, and a very small stream flowing, I have observed more than 50 per cent. to be retained. This result is seen only in the first use of an absolutely sterilized filter.

Speaking of the tank variety of sand filters, it was shown that moistened sand favored the increase of bacteria brought into it by Croton water which had flowed through. In the sand or other granular contents of these filters attached to hydrants, the same multiplication takes place when the water has for some time ceased flowing, and this increase is at a more rapid rate than in water standing in a clean vessel by the side of the filter. The first flow in the morning, for instance, after the filter has remained unused over night, shows a much larger number of bacteria than the hydrant water then contains. Even after the water has flowed for several minutes for the purpose of washing out the filter, the bacteria are in excess over the number in the original water. After such a filter has had the hydrant stream running through it long enough to wash out all the germs that have resulted from the increase (which complete cleansing is not always producible), the bacteria in the water may appear nearly the same in number as in the hydrant water, varying slightly either above or below. While such filters are worse than useless from a bacteriological point of view, they are good strainers when not clogged by too long use without cleansing. As strainers they are less troublesome than flannel bags (which are as safe as these sand filters for use with suspected water, provided that they are removed at least once a day to be disinfected by boiling). The act of reversing this popular sand filter does not cause the removal of the organic matter upon which the bacteria can be nourished. Only the loose outer portion is thereby removed. Such a sand filter is a safer strainer when never reversible, and it should be cleansed at least once a day when needed at all.

Powdered magnesia and other granular substances used instead of sand in the style of filter just described, have no superiority over the easily cleansed sand.

Asbestos board I have not been able to procure of sufficiently firm, strong and fine surface to resist the passage of bacteria under any considerable pressure from the hydrant brought to bear upon such a surface. The quality of the surface seems the important point. To yield a flow of any degree of rapidity, this surface must be large, and that creates a tendency to break and necessitates a bulky filter, which most people shun. Packed asbestos shreds allow a few bacteria to pass through when the sterilized filtering mass is so dense as to cause the flow to be very slow. In this substance, I have, as already mentioned, not observed so marked multiplication of bacteria as in the sand, porous and other filters.

Although large bodies of sand fail to prevent the passage of bacteria with the water which percolates through, it is noticed that certain natural filters of this sort render water much freer from bacteria when the water has first to make its way through a layer of silt, and minute particles which have been arrested by fine sand. It is from the application of this principle that the large filter-beds are built which purify the water distributed by hydrants throughout various cities. Taking as a model the very carefully managed filter-beds of Berlin, it is seen that above the base of the filtering tanks is a layer of a foot of stones, gradually becoming smaller in size toward the upper surface, upon which is coarse gravel to the height of a foot more, then upon this a little more than 2 feet of sand, which at the top is as fine as can be procured. Yet the engineer in charge has recently said that apart from its merit of keeping back the finest particles, the finest sand is not necessary. When the filter-bed has been freshly cleansed, as is found necessary for it after being constantly used for a week or so (occasionally several weeks), purified water is slowly backed into the filtering-mass from below, until this water, carrying up all the air with it, has reached the top of the upper layer. Then the ordinary river (or lake) water is made to flow very gently in, to the depth of 1 meter. This is allowed to stand for at least twenty-four hours. The nitrogenous or other particles, confervoid vegetation and whatever else the water contains as sediment, have, with many micro-organisms, then settled upon the upper portion of the fine sand without sinking deeper, and a delicate film is formed, which, with careful inlet and gentle pressure (never to exceed 2 meters of water), retains nearly all the bacteria of the water supplied, and prevents their passage, provided that the flow through is very regular and slow (never more than 3 meters in a day). With similar filters in Zurich it is found that perfect results are had when the flow is more than four times as fast. Nearly all this separation of the bacteria is produced by the sedimental matter retained on the surface of the sand, so that, when the filter slows from clogging, it is found that less than ½ inch of the upper layer of sand need be removed.

While I have not seen as yet the unpublished report of the elaborate experiments made at Lawrence, on the Merrimac River, under the auspices of the Massachusetts Board of Health, I learn that they inculcate the importance of slow, intermittent filtration for purification of water having much organic matter. I learn on the best authority that these results seem to substantiate the familiar theory that nitrifying bacteria are the most important agent in producing this improvement. This, of course, is true as regards sewage poured upon soil.

On sand-filters as used to purify a bad water for city consumption, it seems to me undesirable to accept this theory as, *e. g.*, Drown does, to explain the great diminution which the best filters cause in the number of bacteria. He, in announcing these results, refers for authority to the presentation of this theory by the engineer of the Berlin water-works, Herr Piefke. The latter, however, when associated with an expert practical bacteriologist, as with Fraenkel in his last article on filtration (see *Zeitschrift für Hygiene*, viii, page 22 and following pages), allows most importance to be attached to the maintenance of the overlying film whose mechanical action is the main reliance. In the article by these two writers, it is asserted that if typhoid germs happen to pass through this film (either by proliferation or owing to a flow) the other bacteria cannot be depended upon to arrest these, even if the water flow slowly. They surmise that the considerable number of cases of typhoid in Berlin during the early part of 1889, probably came from the use of water in which were the peculiar bacteria of this disease, and that these had passed through the filter.

The nitrifying bacteria are important in causing the purification of water, but we, as yet, do not fully understand them. That the felt-like film above the sand of such filters is by far the most important element, is further made probable by the report of Bertschinger (Zurich, 1889), who found that the waters passing through the Zurich sand-filter, became chemically and bacteriologically very pure; yet they flowed through at times faster than at the rate of 36 feet a day, which is very much faster than allowed by the postulates of those who claim that the nitrifying bacteria do most of the work. Still more emphatic are the excellent results where the various proprietary filtering arrangements force water very fast through sand in which, by *e. g.*, hydrate of alumina and silt, a tenacious filtering mass is produced. It is apparently necessary to study each filter-plant by itself, as the conditions of efficient operation seem to vary with the character of the water to be purified.

From the statistics of Wolffhügel, and of Plagge and Proskauer, we learn that the number of bacteria, originally very large in the river Spree, is reduced to a very small percentage in the filtered water, oftentimes a fraction of 1 per cent. I may add that the organic constituents are also decidedly lessened, and that the oxidibility, as tested by the reduction of a standard solution of permanganate of potash, is seen to be regularly lowered one-fourth, and often one-third of the amount shown prior to the filtering. The long arrays of figures given in the reports of the action of these filter-beds show, that with hardly an exception, the ammonia is constantly removed by the process.

In this country the filter-beds, all of which are built upon the same plan as those in Berlin, are less perfect in their action, as the people in charge do not devote sufficient care to sedimentation in the case of those which I am familiar with. Thus, a very carefully planned filter-bed, which filters river-water for one of our cities, allowed, at the time when I examined it, nearly half of the large number of bacteria in the water pumped from the river to pass through. This unsatisfactory result seemed to be due to the fact that too much water was required from the small filter-beds, and hence not enough care could be bestowed upon thoroughness of the filtration.

Of the various large filter systems which I have tested while they were in use in various manufactories and institutions, for which these filters were straining large quantities of water, the only kinds which reduced materially the number of bacteria as found in the hydrant water, were those in which by the addition of a minute proportion of a suitable salt, usually alum (as approved by the general experience of years in many districts), the suspended particles with the organic matter are caused to settle more rapidly, and then these form a deposit upon very fine sand, through which water is forced. From several examinations of a filter of this type, which in every case rendered the water much freer from germs than the original (unfiltered) water, I once found the filtered water wholly sterile, while the (Brooklyn) hydrant water of the neighborhood at the same time showed 397 germs developing from each cubic centimeter. This particular filter was constructed on the principle of Prof. A. R. Leeds, who informs me that the alum was present in the proportion of only 1 part in 100 000 of water. I could not, by the ordinary tests, detect the presence of this salt, and such a small amount can cause no appreciable harm. The alum used is probably decomposed, and its elements taken up by the organic matter and bases present. As previously stated, the sterilization of the water is here caused, not by chemical but by mechanical action, which rapidly produces these excellent results without any recourse to assuming the activity of bacteria of "nitrifying" kinds. In my tests, the typhoid bacillus of the first agar culture from a recent spleen, was not destroyed by standing for forty-eight hours in a solution of ten times the strength of that employed in these filters, while many other bacteria were alive after standing for forty-eight hours in an alum solution of 1 part to 1 000 of water, which sufficed to destroy the typhoid bacillus in that time.

In the present stage of chemical knowledge, there seems no sufficient evidence that in water, these micro-organisms evolve the organic alkaloids which are considered to be produced when harmful bacteria are introduced into the system, and by their action there cause disease. What the exact nature of the volatile organic constituents carried over in distillation may be, and whether they are in any way deleterious or not, rests for the science of the future to determine. The process of boiling previous to vaporization in the still, must kill all harmful bacteria, and all other bacteria that I have ever encountered, in the original hydrant water from which such water is prepared. The bacteria which I have found in specimens of distilled water, must have been introduced from without after the water was condensed from the still, and before the bottling process was completed, but in this I have never found any other than harmless varieties. Water condensed from various stills of approved patterns I have found sterile. The relatively large amount of free ammonia found in such distilled waters (it being several times greater than any detected in the Croton hydrant water) does not seem to me to be objectionable. The condensed steam produced in distilling, represents a much larger original amount of water than results after the process of vaporization and condensation is completed, and the ammonia may besides come from the air and from other sources.

To those who desire a water freer from alkaline earths than the ordinary "hard" water which they may have to drink, it should be mentioned that the process of heating, in the sterilization by boiling which I so urgently recommend when it is necessary to drink suspected water, drives off free carbonic acid, and so causes the deposition as an insoluble sediment, of the carbonate of lime and other objectionable salts which form the so-called "temporary hardness." The water is thus rendered "softer."

When boiling is resorted to because of actual infection of the water, it should be carefully done. It is best to have the water, perhaps after a preliminary boiling and straining, decanted into bottles, each holding, say, a quart, and these covered with a suitable glass cap, or plugged with cotton, or provided with a clean stopper loosely dropped in, and then the bottles placed in a kettle or cauldron in the absence of a steaming apparatus. This is heated and kept near the boiling point for half an hour. Then the whole is allowed to cool, and the bottles may be placed near ice; but in the water thus carefully prepared it is not advisable to put ordinary ice, for harmful bacteria may retain their vitality in ice longer than in water. Pure water loses all its excellence when unwholesome ice is melted in it. For those to whom the taste of boiled water is unpleasant, weak teas, wine or other savor may be added to mask the absence of the more agreeable taste imparted by the process of aërification (which under ordinary conditions may itself be a means of adding bacteria to the water).

SUMMARY.—Boiling sterilizes water, and within less than five minutes will have killed harmful bacteria of any kind that are liable to occur in water.

Drugs and other agents acting chemically, if used in amounts which are commonly safe, do not sterilize water till after an impracticable lapse of time.

The prolonged heat which water undergoes in the usual process of distillation, destroys all germs which may be in the water undergoing the process.

Ordinary filters, even if satisfactory as strainers, fail to remove all bacteria from drinking-water. So far from lessening the number in the original water, the filtering substance may allow a more rapid multiplication than these micro-organisms would ordinarily undergo in the unfiltered water on standing; and the germs of disease, even if held back by the filtering substance, may be harbored in all filters.

The finer the substance through which the water passes, the lower the pressure and the slower the flow, the more perfect is the action of the filter in holding back the bacteria.

Of all substances thus far furnished for domestic filters, porous rebaked porcelain, carefully selected, I have found to be the best. If thick and strong enough to allow the use of a large surface, and the substance remain perfect (without flaw or break), this may yield a fair flow of clear water, free from all bacteria; yet under our ordinary Croton pressure of one atmosphere or less, this yield is only in rapid drops, unless the apparatus be complex.

To insure the permanency of this action, the filter should be occasionally sterilized throughout, by steaming or by other means; for under prolonged pressure, various kinds of bacteria can go through, and in the copious organic matter collected on the filter some harmful micro-organisms can retain a high degree of vitality for weeks longer than I have ever found them to live in pure water.

Where filtering is really necessary, it is generally best for the community that it be done carefully on a large scale through sand-beds upon which a fine layer of organic and inorganic matter is expressly produced by sedimentation, because of its valuable action in holding back the great majority of the bacteria.

A bad water, filtered, is less desirable than a pure water in its natural state. When, therefore, filtration is employed because of real danger of infection, the filtered water should, as a rule, be furthermore boiled, as the entire absence of sediment and cloudiness does not insure that the bacteria of disease may not have made their way through the filter.

DISCUSSION.

Charles B. Brush, Director Am. Soc. C. E.—Does the pressure in the pipe tend to reduce the vitality of the bacilli ?

Dr. Currier.—Not necessarily; it may somewhat.

Mr. Brush.—Do muddy rivers and rivers carrying a large proportion of silt have a tendency to reduce the actual amount of life ?

Dr. Currier.—That depends on the composition of the silt.

Mr. Brush.—When silt is removed by settlement from silt-bearing rivers like the Missouri, does this settlement remove the bacteria in water ?

Dr. CURRIER.—Such settling may remove some. But sedimentation is most effective when caused by the artificial introduction of lime, as at St. Louis, or by alum, which is used in some large filters. An organic combination is thereby formed which carries down more particles than do settling particles of sand or other heavy particles.

Mr. WM. E. WORTHEN, Past President Am. Soc. C. E. said: Dr. Currier states, "The best deep springs show few or no bacteria; and uncontaminated water flowing directly thence is, unless highly impregnated with minerals, the most wholesome of beverages." It has been my experience that such well-waters develop algæ readily and abundantly when exposed to the air, as in all cold household springs these algæ invariably hang around the barrel, in the well-water supplies of Newton and Waltham, the water supply of Fort Wadsworth, Long Island City and East New York, which last were under my charge. Protecting the reservoirs and springs from air and light has, when tried, invariably stopped their development. The function of these algæ, as generally received, is to supply oxygen to the water in form of solution, and not mechanically. Although algæ are not generally considered dangerous to life, or detrimental to health, they are objectionable to consumers on account of the color given to the water in their life, and the taste and smell by their decease. It has been a question with me whether the water would not be better if the algæ were left to develop and absorb, whilst living, into some higher organisms. I have propounded this question to our member, F. P. Stearns, of the Massachusetts State Board of Health, with the following reply: "I suppose that ground water does contain less oxygen than surface water, although it will acquire it in a very short time on standing. I do not understand that it contains the undeveloped germs, but rather the food upon which the germs of algæ already in the reservoir thrive, and I think it may be a question whether horse sense is to be trusted. With regard to the death rates from a disease like typhoid fever, I believe that during the last eighteen years there have been 10 per cent. more deaths from typhoid fever at Lawrence than at Lowell, and more deaths at each of these places than at most large places in the State. There is one city, however, with an unpolluted water supply, which has had 50 per cent. more deaths from this cause; and the variations between other cities which have equally good water supplies are greater than between Lowell and Lawrence, showing that other causes have a greater effect than the water supply."

Time is a very large element in determining the value of facts and the inductions from them. Dr. Wolcott, in his address as President of the Public Health Association, says: "Unfortunately, man's life is hedged about with many injurious influences, which we do not understand accurately, and which we cannot remove.

"In several cities of Massachusetts, epidemics of scarlet fever, as well as of diphtheria, have been recorded, under conditions that can leave no doubt as to the accuracy of the observation, which have at some seasons shown a marked activity in well-drained and otherwise well-cared-for districts, and have had but limited development in other portions of the same city, where drainage is defective and crowding marked.

"The difficulties of interpreting vital statistics, for the purposes of the sanitarian, are by no means small. We have not been gathering them for periods of time sufficiently long, over territories sufficiently wide, to justify definite conclusions upon a large number of public health questions. Before the beginning of the Christian era, the bubonic plague was the one great epidemic of the middle ages. The pestilence raged with such fury that 100 000 persons perished in London in 1665. The retreat had already begun when London was burning, and Western Europe, by no effort of her own, was at last free from the most fatal epidemic of modern history. In the years from 1800 to 1804, scarlatina was prevalent in Ireland, and very fatal, while in the succeeding years, down to 1831, the disease had so far changed its character that physicians in large practice could say that they had never seen a fatal case. Therefore medical men were led to believe that this change was the result of better treatment. In 1831, however, an outbreak of scarlet fever took place which had all the characteristics and all the malignancy of the earlier epidemic."

I would also refer further to Dr. Wolcott's and Dr. George M. Sternberg's address as Presidents of the American Board of Public Health, as to the value of plate culture of organisms and of the sterilization of water.*

"With regard to the development of typhoid fever and cholera, the literature is very extensive, and hygienists have not yet arrived at any settled theory; they neither agree upon their facts or upon the causes. We believe with Dr. Currier that water becomes purified by flowing as a fact, and as a necessity that there must be some means provided by nature to destroy the excess of pathogenous microbes. If it is done by saprogenic microbes, or the bacteria of putrefaction, it might be well to increase the production of these last, and let higher organisms absorb the survivors—keep the aquarium balanced. In fact the pathogenic organisms must be very much in the minority, and subject to many destructive influences. It is doubtful how far certain pathogenic forms are specific causes of the disease in which they have been found in the tissue. The pneumo-coccus is announced as the germ of consumption, and yet there are microbes in the normal saliva of man which by injection produce the same results as the pneumo-coccus.

"Numerous bacteria exist in the digestive canal of a man in good health. Recent researches tend to show that these microbes are not only

* Troussart on "Useful Microbes."

innocuous, but that they play an active part in gastric digestion, and especially in the transmutation of albumens into peptones. Since they are, in fact, living ferments, the transmutation is retarded if these microbes are eliminated. It is therefore probable that they manufacture pepsin." Pasteur's experiments also tend to show that microbes aid the germination of plants. "If the microbes contained in vegetable mould are withdrawn from it, without taking away any constituent, germination is retarded and effected with difficulty." If they are withdrawn from the animal frame, may not the same effect be produced on generation.

We take into our system some half a million microbes per day, which, according to some medical authors, are the food of the phagocytes or leucocytes, on which the healthfulness of the blood depends. Whether it is so or not, in view of the immense numbers and diffusion of microbes, it is evident it will be impossible to try the experiment of complete sterilization.

The literature of microscopy is pleasant reading, but it should be supplemented by a comparison with death and disease rates, and by practical observations of what we can see directly with our eyes.

The office of Vital Statistics is the most important one in our Boards of Health; the officer in charge should be intelligent and active, results should be tabulated and published, and all the conditions should be noted bearing at all on the probable cause of the disease.

Prof. Albert R. Leeds.—In attempting to discuss the extended paper of Dr. Currier, there is considerable difficulty, due to the many disputed points he has touched upon, and the necessity of often-repeated and most careful experiments requisite to arrive at anything like definite conclusions of practical value. In the first place, the views of Pettenkofer and the champions of the so-called "ground-water theory" of the causation of epidemics, are placed in comparison with the more recent "drinking-water theory," and the author presents no very definite conclusions as to the truth or falsity of either. I have supposed that it would reflect the views of the majority of those who have followed the long-continued controversy on this subject, to assign to the hypothesis of Pettenkofer and the Munich school a historical value mainly, while the great consensus of opinion is definitely in favor of the hypothesis which has been worked out by the more exact and more advanced experimental methods adopted by Pasteur, Koch and their host of followers.

The author states his belief that a water containing a large number of bacteria, especially if many varieties are detectable, is undesirable as a beverage so long as it has not undergone the sterilizing effect of heat. From the form in which this statement is put, it would seem that such a bacteria-rich water would be desirable as a beverage after it had undergone the sterilizing effect of heat, and I desire to learn whether this is the author's meaning.

Furthermore, in the case of any particular water, how many bacteria and how many varieties should it contain before it would become undesirable before, and desirable as a beverage after, it had undergone heating. This is a practical question of immediate importance to the water-drinker. The Croton water, for example, frequently contains over four hundred colonies per cubic centimeter, and sometimes has over one thousand. The author found in the Delaware River, at Water Gap, three thousand four hundred colonies. This water, on the score of chemical purity, was recommended by the officers of the survey for the future supply of Philadelphia. And yet the number of bacteria is twice that reported by the author as present in the Passaic River, which, on the score of both common observation and chemical analysis, is one of the most polluted streams in this country.

Is it not true, as a matter of fact, that the one thousand colonies in the Croton water, the three thousand four hundred colonies in the Delaware water, weigh but little in the estimation of the bacteriologist if he feels sure on other grounds that the Croton water-shed, and the Upper Delaware water-shed, are demonstrably free from sources of serious sewage pollution?

I should be glad if the author would point out how the very few figures he has given, establish the fact of the self-purification of the streams examined. In the case of the Mississippi, the Passaic, the Delaware and the Schuylkill, there is an increase in the stated number of bacteria as we go down stream—how is this to be reconciled with the idea of self-purification. Also, if the author were to explain in what manner the old Croton Aqueduct affords opportunity for thorough aërification of the Croton water; which although dark throughout, and apparently different in many respects from ordinary flowing streams, is properly to be regarded as an ideal stream, and one admirably adapted for testing the question at issue.

In the same connection Dr. Currier calls attention to the fact of a slight epidemic of typhoid fever at Port Jervis, on the Upper Delaware, beginning October 1st, 1883; and apparently connects it with an outbreak of typhoid in Philadelphia, in January, 1884. Are we to understand his recommendation that the water should come to Philadelphia from a remote location through an aqueduct, to mean, that if so conveyed, the typhoid germs emanating from Port Jervis would have been destroyed; whereas with the apparently possible opportunities of self-purification afforded in so great a flowing river as the Delaware, they escaped destruction in the flow of more than a hundred miles.

It is important to bear in mind that the results of bacteriological examinations vary enormously, when they are made at different times and under different conditions. As an illustration I would quote the condition of the Passaic River during the summer and autumn of 1887. Those who are interested will find in the reports to the Newark and Jersey City Aqueduct Boards from 1881 and 1886 the chemical evidence, on which I was led to infer that the large amount of sewage introduced at Paterson was oxidized at such a rate, that in case no further sewage were introduced lower down, the Passaic would have returned to the same condition as above the Great Falls during a flow of 16 miles. The reasoning is based upon the fact that while the dissolved inorganic substances go on steadily increasing in amount, the dissolved organic compounds exhibit a progressive diminution. A similar fact was noted in the condition of the Hudson River after receiving the sewage of Troy, and is stated in the reports to the Albany Special Water Commission. Also in the reports of the Philadelphia Water Department, as true of the improvement in the character of the Schuylkill River water, in its flow of 7 miles below the influx of the sewage from the town of Manayunk. In the case of the Hudson River, a corresponding series of biological analyses was made of the waters below Troy; and while the biological analyses did not correspond exactly with the chemical, the decrease in the number of bacteria as a general rule, corresponds with the oxidation of the dissolved sewage contamination.

Besides the evidence contained in the reports above alluded to, showing the dangerous pollution of the Passaic River, there is a further report, made at the desire of my colleagues of the State Board of Health in the year 1887, in which are given the results of a combined chemical and biological examination. In that report the condition of the Pequannock River above Butler is taken for comparison, and its great chemical purity is shown, with the corresponding low number of bacteria, of 70 colonies per cubic centimeter. The monthly analyses of the Hackensack River during the past 5 years having shown that with the exception of its somewhat high percentage of peaty matters, it was otherwise pure, this was examined and it was found to contain at the time of the investigation 200 colonies per cubic centimeter. But the Passaic, above the Great Falls, contained 4 000 colonies, while below, after receiving the Paterson sewage, they were innumerable. One mile below Paterson there were 72 000 colonies; and two miles below, 64 800. These enormous numbers are evidence certainly of great pollution, and at the same time of an apparent progressive improvement going down stream.

But other tests made lower down did not show such a progressive improvement, nor can I well see how this was to be anticipated, considering the variable increments of sewage coming in at the city of Passaic, the second river, the third river; and what is carried up stream even beyond the Newark and Jersey City intakes by the tidal flow, carrying with it the sewage emptying into the Passaic from the city of Newark. So that while thirty determinations of the number of bacteria at different points were made, they appeared insufficient to generalize from. I shall simply note here, as a point less studied perhaps by other observers, that the Passaic River below Paterson, where the colonies of bacteria were so numerous as to defy counting, contained in solution but 2.97 cubic centimeters of oxygen per liter, while above the Great Falls it had 6.57 cubic centimeters. The Pequannock exhibited nearly the point of saturation with oxygen, or 7.22 cubic centimeters. So far as the evidence at present in our possession is concerned, it appears to show that with the incursion of sewage into a stream, whether from sewage or drainage, its content of dissolved organic nitrogen rises, and at the same time the number and variety of bacteria, while the percentage of dissolved oxygen sinks; and that when this sewage is submitted to the action of the various nitrifying and other bacterial ferments in a flowing stream, its organic nitrogen is oxidized, and the sewage is progressively destroyed. The evidence would appear to show that the multiplication of bacteria first takes place; then afterwards, along with the destruction of sewage, their progressive diminution. Such appeared a fair construction to put upon the results of the examination of the water of the Hudson River after receiving the sewage of Troy, of the Schuylkill water after receiving the sewage of Manayunk, and of the Passaic after receiving the sewage of Paterson. But a vastly greater number of analyses and determinations are needed, to speak with certainty upon these points. Similarly the number of bacteria in the Croton water varies between very wide limits. It may fall much below a hundred, and again it may rise, after a fall of rain or an increase of temperature, above a thousand. But except for the reason that the sanitary cordon around the streams on the Croton water-shed is not as yet rendered perfect, I don't think any one would seriously suspect that, even with 1 000 bacteria per cubic centimeter, the Croton water is necessarily dangerous to drink. And such is the character of these variations, that while the figures given by Dr. Currier show a diminution along the course of the Croton Aqueduct, an eminent bacteriologist, especially familiar with the Croton water, stated to me that at times these figures would be reversed.

Rudolph Hering, M. Am. Soc. C. E.—The subject of Dr. Currier's paper is certainly one which is of great importance to those engineers whose business it is to arrange for water supplies and disposal of sewage. I was in hopes, inasmuch as there is still a great deal of darkness on the subject, that Dr. Currier would give us a large amount of additional light which would help us in our work. But, while I think his paper is a very able exposition of much of the matter known at the present time, I was disappointed to see that little had been done lately which could be of much assistance to us.

Regarding his statement of the different theories held in Europe and America as to the relation which the height of ground water holds to the prevalence of certain diseases, I recall an interview I had some years ago with Dr. Pettenkoffer on this subject, when I was surprised to see the strong evidence which had been collected. The tables he showed me were certainly remarkable, as demonstrating the relation of the mortality of typhoid to the ground-water level in Munich. Later I saw similar tables for Berlin and other cities of Germany, all of which showed that when the mortality was high the ground water was low, and vice versa. I thought at the time, and this idea seems to be held by a good many, that the explanation of this peculiarity might be as follows: the time when the ground water is low and the death rate is highest, corresponds with the time when the streams are low. The pollution derived from the soil, from manure and decaying vegetable matter, is then relatively greatest; and during long dry spells there is also a great deal of dust in the air, which settles upon the water more than at other times. But the "drinking-water theory" is also supported by strong evidence, as, for instance, by the epidemics at Plymouth, Pa., and many other places. Yet we have cases which are authentic, showing that typhoid fever could not have been transmitted by drinking-water. It therefore seems as though neither theory were quite satisfactory, but that the modern assumption, that the bacteria or their products are the real cause of the disease, may reconcile both of the older ideas.

Chemistry alone does not seem sufficient to determine the presence of these bacteria, as I am informed that there may be 500 000 in a cubic centimeter without being discovered through any chemical means. I was in hopes to hear something about the typhoid bacillus, which seems to be especially important. The Massachusetts State Board of Health is about to experiment with this bacillus, and to ascertain, if possible, its life and behavior in soils and water. This board is doing some excellent work, which will undoubtedly help the engineering profession very much. I do not think that anywhere in the world there is such a fund of facts relating to the purification of water as this board has collected.

In enumerating the various causes for the disappearance of organic pollution in water, Dr. Currier mentions deposition, by which bacteria tend to settle. He also mentions a number of instances which show that oxidation and the development of bacterial life is restricted by light. The English Rivers Pollution Commission, through the works of Dr. Frankland, who was in charge, seemed to show quite the contrary, namely, that light rather invited oxidation. They say that such oxidation is more active in sunshine than in shade, and is almost entirely arrested at night, or when the thermometer approaches the freezing point, showing that oxidation depends on the same conditions as those favorable to the life of low organisms. It may be, however, that more recent investigations have shown that these assertions need qualification.

Regarding large filters, Dr. Currier says that when they are carefully managed they effect great improvement in inferior waters. It is precisely on this subject that the Massachusetts State Board of Health has reached some definite and more or less new results. They have erected ten large filter-beds, consisting of tanks, each 16 feet in diameter, and filled with different kinds of material, such as coarse sand, fine sand, loam, garden soil and peat. They have experimented not only with the water from the city supply, but also with sewage. The results obtained differ in some respects from what has formerly been supposed to be true. For instance, it has been found that peat, which is mentioned in different works as being a good material with which to purify sewage, is not at all capable of purifying it for any length of time. The board find that the purification of water depends on the physical condition of the material through which it filters, on the fineness of its grains, on its porosity, on the continuity of the pores which permit the air to follow the water or sewage when it is intermittently applied, and upon the presence of bacteria which effect the nitrification of the organic matter.

In experimenting with different kinds of soil, different degrees of porosity, etc., the board find that the best material for purifying sewage is sand of the fineness of common mortar sand. That the purification is not a straining process, they have proved by pouring sewage upon coarse gravel stones, 5 feet deep, from which all sand had been washed. When applied intermittently, a little at a time, at the rate of 80 000 gallons per acre daily, "each stone was kept covered with a thin film of liquid, very slowly moving from stone to stone and continually in contact with air in the spaces between the stones. The liquid, starting at the top as sewage, reached the bottom within twenty-four hours with the organic matter nearly all burned out."*

The board has further found that a certain time elapses before the nitrification sets in, and that by a persistent application of water or sewage the capacity of a given filter can be increased. It has been found that "a bed of coarse mortar sand, having particles about $\frac{5}{100}$ of an inch in diameter, there can be filtered intermittently for an indefinite period —*i. e.*, year after year—from 50 000 to 100 000 gallons of ordinary city sewage upon an acre, daily, without any accumulation of filth in the sand after the first year, and giving a bright, clear, colorless water, which chemical and biological analysis show to compare favorably with water from some of the wells used for drinking in some of the thickly settled parts of towns and cities in this State"* (Massachusetts). With finer sand, having grains which were but $\frac{5}{1000}$ of an inch in diameter, there could be filtered daily from 15 000 to 30 000 gallons per acre with a complete removal of all bacteria, and with a purity greater than that of most of the drinking-water supplies of the State.

The water used in Lawrence for domestic purposes when filtered through fine sand, could be applied at the rate of 3 000 000 gallons per acre, and thereby be rendered pure.

While the principles of purification through sand are not directly applicable to the purification of polluted water in streams, yet they may give us a clew by which we may also determine under what conditions

* "Lend a Hand," September, 1890.

we can best purify foul waters when mingled with the comparatively pure waters of running streams; for that reason I thought it might be of interest to mention the results which have been reached in Massachusetts.

The CHAIR.—Are these results contained in the last reports of the board?

Mr. HERING.—Some of them are, and others appeared in print in a short paper, published not long ago, written by Mr. Mills, who conducted the experiments.

Mr. WORTHEN.—The results, as I understand, will be published in full in the report of January.

Mr. HERING—I would like to ask Dr. Currier whether he took account of the question of dilution when he gave the number of bacteria in a cubic centimeter of water; many of these results seem to prove the reverse of what he wishes to prove regarding the self-purification of streams. In the case of the Kaaterskill brook, if I remember rightly, he gives 54 bacteria per cubic centimeter, and $1\frac{1}{2}$ miles below that point he gives 49. Now, if in that $1\frac{1}{2}$ miles this brook increased its flow 10 per cent., it would show that the same number of bacteria were contained in the cross-section, and that, therefore, there was no diminution in the number of bacteria. Again, in the case of the lake in the Rocky Mountains, he says there were 154 bacteria per cubic centimeter in the stream leading to it, and in the lake, which is quite large, he finds 43 bacteria in a cubic centimeter. It therefore seems that in going down stream, the total number of bacteria in the water is increased. But in many cases no doubt the reverse is to be found.

Dr. CURRIER.—Mr. Hering speaks of my wishing to prove a certain point; I merely show the result of a perfectly impartial investigation; the paper is simply a presentation of facts as I found them.

It must appear unsafe to consider that a river sufficiently purifies itself within a short distance from the entrance into it of a considerable amount of sewage or other contamination.

The slow filtration, which proved so satisfactory in certain of the Massachusetts experiments, produces very much purer water than is obtained when a large volume of bad water is rapidly passed through the usual large sand filter.

J. J. R. CROES, M. Am. Soc. C. E.—That the drinking of water may produce or aggravate disease in the human body, has been conceded by physicians for a great many years. The exact conditions of water under which injurious effects may be produced, have been the subject of investigation by a number of different classes of observers. Up to a very recent period the chemical composition of the water was the only subject of investigation, and disease was supposed to be dependent on the chemical action of certain constituents in the water on the tissues of the body. About fifteen years ago it became evident, as the result of progress in microscopical and chemical investigation, that the forms of animal and vegetable life which are to be found in waters generally only by microscopical examination, produced, by both their growth and decay, certain effects upon the human system, without, at the same time causing any very material change in the chemical constituents of the water.

The vegetable organisms are classified as algæ, and have been discussed at some length in papers heretofore presented to the Society. There are also found in water, however, great numbers of what is now considered to be the lowest form of animal life, the organisms classified under the general head of bacteria, which are visible only under a microscope of high power, being generally less than the one-five thousandth part of an inch in length. These small creatures possess, however, a decided individuality, and are found to be divided into numerous families, each differing from the other in shape, size and color.

The careful investigation of Dr. Koch and other scientists appears to have established the fact, that certain species of these infinitesimal creatures are found in considerable quantities in the human body, only where certain diseases are known to exist, and the presumption is, therefore, that such diseases are produced by these species. These bacteria are found in water, and it may safely be assumed that where a water contains a large number of such species as are known to exist in certain tissues of the human body, only when these tissues are known to be diseased, such water cannot safely be taken into the human system. The reason for the appearance, growth and disappearance of these organisms in waters has not been accurately determined; but that injurious species do appear in running streams, and that the number of them increases or diminishes as the case may be, is well established. The object of the investigations, the results of which are embodied in Dr. Currier's paper, has been to discover more particularly whether in a running stream, in which at some point on its course an excessive number of these injurious bacteria have been discovered, there will be an increase or a diminution of such organisms in the course of the natural flowing of the stream through a channel, in which no apparent exciting cause for their generation or growth has occurred.

The method of investigation of these organisms is as follows: A preparation of ten parts of strong beef tea and one part of gelatine is submitted to steam heat long enough to kill any bacteria which may be in it, for it has been found that these small creatures cannot stand boiling. This mixture solidifies in cooling. While the gelatine is soft (at a temperature a little above 73 degrees Fahr.), 1 cubic centimeter or about a quarter of a teaspoonful, of the water to be examined, is added to the gelatine drop by drop, and the bacteria in the water are diffused throughout the gelatine by rotation of the containing tube. The mass is poured into a shallow glass dish and carefully protected from the contamination of the air, and allowed to solidify. On examination with a microscope a few days later, the individual bacteria in the water which has been added are found to have increased and multiplied to an enormous extent, each individual being now the center of a mass of many thousands, and even millions, of individuals. These masses, called colonies, are visible to the naked eye, and their appearance differs greatly. The number of the colonies is counted, and this number affords some criterion of the quality of the water.

To know whether the individuals composing these colonies are injurious or not, reference must be had to the investigations made by the scientific observers of bacteria. Many of them are supposed to be perfectly harmless, while others are pretty well proven to be disease-producing. The character is discovered by finding out what food they thrive on best, and what forms they assume in generation and growth. For this purpose various "culture media" are prepared, which are concentrated extracts of various nutritious substances, stiffened with gelatine or similar substances, and put in test tubes. A fine platinum wire, having been first passed through flame to kill any germs which may be on it, is touched to a "colony" and then plunged into a tube containing a "culture medium." The bacteria thus transplanted generate in a few days; and their growth and form can be studied under the microscope, and their class determined from their form and their rate of growth in that "culture medium."

Now, by taking samples of water in a stream at any point, and taking other samples of, as nearly as may be procured, the same water at another point lower down on the stream and treating both samples alike, it is possible to determine both whether the bacteria have increased or diminished in number, and whether such change of number has been greatest in the injurious or the harmless species. In general, if the number has greatly diminished, it may be assumed that the quality of the water has improved, for the harmless varieties are the more hardy, and appear moreover to destroy the injurious ones when they are brought into conjunction with them, without the addition of fresh supplies of bacteria from foreign sources.

George W. Rafter, M. Am. Soc. C. E.—Dr. Currier's paper discusses one phase of the question of self-purification of water in flowing streams. There are, however, other phases of considerable importance, and the following, without exhausting the subject, may be taken as a partial view of some of the causes operating to produce such self-purification.

Among the invertebrata there are certain classes of microscopic animals which, under favorable conditions of sufficiency of food supply, multiply in enormous numbers. As common representatives of these minute animals, we may mention: (1) certain of the filth infusorians, as for instance *Paramecium;* (2) *Hydra*, as the typical representative of the order Hydroida; (3) certain of the Rotifera, of which *Lacinularia* and *Conochilus* may be cited as perhaps typical forms; (4) the numerous species of animals included in the entomostracan crustacea; (5) *Gammarus*, or the fresh-water shrimp; and (6) the larvæ of a number of water insects.

In comparison with bacteria the infusoria are creatures of vast size, even though some species are as small as $\frac{1}{1000}$ inch in length. *Paramecium aurelia*, a form found I believe almost invariably wherever putrefaction of animal matter is taking place in water, is an infusorial giant, mature individuals measuring as much as $\frac{1}{96}$ inch in length. *Paramecium bursaria*, however, is much smaller, about $\frac{1}{280}$ inch being the usual length.

In addition to *Paramecium*, there are a number of other ciliate infusorians, which are almost invariably found in water containing organic matter undergoing decay, and examinations made by the recently developed methods of biological enumeration, indicate that from twenty to fifty such forms may be found in every cubic c.c. of badly contaminated water; but whether any such numbers would be found in running streams, even though flowing slowly, I have had as yet no means of determining.

Any notice of the infusoria in relation to the self-purification of contaminated waters, would be incomplete without some reference to *Euglena* and the allied genera. In standing waters *Euglena viridis*, an infusoria of bright green color, is frequently present in such quantity as to impart a green color to the water. Its length varies from $\frac{1}{140}$ inch to $\frac{1}{600}$ inch. The vast quantities of *Euglena* which are met with under favorable conditions are sufficiently accounted for when we learn that it may multiply, not only by fission, or by the division of one individual into two, but it further multiplies by the "subdivision of the entire body substance into sporular elements, and by the development of independent germinal bodies out of the substance of the endoplast."*

Euglena is generally found in quantity in streams contaminated with sewage. *Hydra* is an animal of considerable size, frequently reaching a length, when fully extended, of nearly an inch. It is attached to water plants in quantity in stagnant waters, and voraciously devours everything coming within its reach.

Rotifers frequently develop in vast quantity in waters carrying large amounts of organic matter; and among such *Lacinularia socialis* may be taken as typical. This creature is usually attached to water plants along the margins of slowly running streams; and in favorite locations at certain seasons, many hundred thousand colonies will be found in a limited space. The colonies are about $\frac{1}{5}$ inch in diameter, and frequently contain from fifty to one hundred individuals, each about $\frac{1}{12}$ inch in length. A single sprig of water plant has been found to support nearly one hundred colonies.

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* Kent, "Manual of the Infusoria," page 379.

Another rotifer which may be mentioned is *Conochilus volvox*—a free-swimming, social form—with the colonies containing from seventy to one hundred individuals. The colonies are on an average $\frac{1}{20}$ inch in diameter, with the single members $\frac{1}{40}$ inch in length.

Probably the Entomostraca are of the animal forms the most efficient assistants in the self-purification of running streams. The vast numbers in which they develop, and the readiness with which they devour all sorts of filth, render them worthy of more extended study, from an economic point of view, than they have yet received.

As illustrating the forms especially worthy of attention, in this connection, may be mentioned *Daphnia*, *Ceriodaphnia*, *Cypris*, *Cyclops* and others. These are all found in waters containing decaying organic matters, and if the water is intended for domestic use, their presence in quantity may be taken as danger signals.* On the other hand, their presence in quantity may be taken to indicate a step in the process of self-purification of contaminated waters. As many as one thousand four hundred *Ceriodaphnias* have been counted in a single quart of such water,† and this number by no means exhausted the visible life in the sample.

A study of the Entomostraca, and observations of their immense fecundity and tendency to act as scavengers, led at an early day to singularly correct views as to the causation and spread of disease. Thus Otho Fredericus Müller, in his work on the Entomostraca, published in 1785, says: "The time is at hand when the causes of disease shall not only be sought after in the air, in our method of living, etc., but in the incautious use of waters often abounding in innumerable animalcules." The fertility of these little animals has already been referred to, and by way of illustrating it, reference may be made to Jurine's computation, that a single female *Cyclops quadricornis* might in one year have a progeny amounting to four billion, four hundred million.‡ The following are the average lengths of some of the animals of this group: *Daphnia*, $\frac{1}{10}$ inch; *Simocephalus*, $\frac{1}{8}$ inch; *Cyclops*, $\frac{1}{10}$ inch; and *Cypris*, $\frac{1}{12}$ inch. *Gammarus*, another crustacean of the order Amphipoda, is a denizen of sluggish-flowing, contaminated streams, where it may be frequently found in great quantity. This animal, when full grown, attains a length of $\frac{1}{2}$ inch. The larvæ of a number of insects pass their larval stage immersed in water, and among such the larva of the mosquito may easily take a high rank for large numbers.

The foregoing exhibits, in a very incomplete way, a few of the animals which assist in the self-purification of a running stream. The number of species which actually assist in such work is very great, and a mere enumeration of them would require considerable space. As to the

* Herrick, "Crustacea of Minnesota."

† Herrick, *loc. cit.*

‡ Baird's "British Entomostraca," page 190.

definite part played by each species little can be said, as, with the exception of the Entomostraca, none of them have been studied in reference to their economic value in this direction. The exception noted in the case of the Entomostraca is a partial study made by Dr. H. C. Sorby, of England, a few years ago.

Enough can be gathered, even though we possess little definite knowledge, to justify saying that animals of the classes under consideration play a very important part in the so-called self-purification of streams. Minute plants may also be considered as assisting greatly in such work, but this part of the subject I leave untouched at this time.

The question of self-purification may, however, be somewhat simplified, if we consider just the distinction which marks the division line between animals and plants. The specific difference may be readily appreciated, by considering that animals always require organized food; they seek those substances in which hydrogen, nitrogen, carbon, sulphur, etc., have been already assimilated into living forms, such living forms themselves being either animal or plant. Plants, on the other hand, have no power of assimilating organized food; they require rather the elements hydrogen, nitrogen, carbon, etc., in their primal state. In a general way, it may be said that this distinction holds good through the whole scale from the highest to the lowest. Indeed, when we come to deciding a difficult case, as for instance whether a given form belongs to the Protophyta or the Protozoa, we take advantage of this distinction, and the natural line of study is to determine in which way food is taken by the unknown form.

A proper appreciation of this distinction will assist greatly in understanding the phenomena exhibited by streams in the process of self-purification. Thus we seem justified in concluding, that if contaminating organic matter in streams is to be reduced to an innocuous form, without the intervention of foul, odor-producing, putrefactive processes, it will be accomplished, in the earliest stages at any rate, by the assistance of animals rather than plants. Just how animals and plants assist in the process of self-purification, is finely exhibited by the paper of Dr. H. C. Sorby herewith appended, entitled, Detection of Sewage Contamination by the Use of the Microscope, and on the Purifying Action of Minute Animals and Plants. Dr. Sorby says:

By studying with the microscope the solid matters deposited from the waters of a river, the previous contamination with sewage can usually be detected without any considerable difficulty. If the amount be serious, the characteristic particles of human excrement can easily be seen; and if it is small and has been carried a long way by the current, it can usually be recognized by means of the hairs of oats derived mainly from the droppings of horses, which resist decomposition for a long time, and are not consumed as food by minute animals. I, however, do not propose to enter into detail in connection with this part of my subject, but specially desire to call attention to the connection between the number of minute animals and plants and the character of the water in which they live, and also to their influence in removing organic impurities.

For some time past I have been carefully ascertaining the number per gallon of different samples of river and sea water, of the various small animals which are large enough not to pass through a sieve, the meshes of which are about $\frac{1}{200}$ part of an inch in diameter. The amount of water used varies from ten gallons downwards, according to the number present. By the arrangements used there is no important difficulty in carrying out the whole method in a satisfactory manner. I confine my remarks entirely to general mean results. The chief animals met with in fresh water are various Entomostraca, Rotifera and the worm-like larvæ of insects. I find that the number per gallon and percentage relationships of these mark, in a most clear manner, changed conditions in the water, the discharge of a certain amount of sewage being indicated by an increase in the total number per gallon, or by an alteration in the relative numbers of the different kinds, or by both. All my remarks apply to the warm part of the year, and not to winter.

It is known that Entomostraca will eat dead animal matter, though probably not entirely dependent on it. I have myself proved that they may be kept alive for many months by feeding them on human excrement, though they soon died without it. If the amount of food in any water is small, not many of such animals can obtain sufficient; but if it be abundant, they may multiply rapidly, since it is asserted that in one season a single female Cyclops may give rise to no less than four thousand millions of young. In stagnant muddy ponds, where food abounds, I have found an average of 200 per gallon. In the case of fairly pure rivers the total number of free-swimming animals is not more than 1 per gallon. I found, however, that where what may be called sewage was discharged into such water, the number per gallon rose to 27, and the percentage relationships between the different groups of Entomostraca were greatly changed. In the Thames at Crossness, at low water, the number was about 6 per gallon, which fell to 3 or 4 at Erith, and was reduced to less than 1 at Greenhithe.

There is, however, a very decided limit to the increase of Entomostraca when the water of a river is rendered very impure by the discharge of too much sewage, probably because oxygen is deficient, and free sulphide of hydrogen present. Such water is often characterized by the great number of worm-like larvæ of insects. Thus, in the Don below Sheffield in summer, I found the number of Entomostraca per gallon only about one-third of what it is in pure waters; whilst on the contrary, the number of worm-like larvæ were more than 1 per gallon.

Now, if the minute free-swimming animals thus increase when a certain amount of sewage supplies them with ample food, it is quite obvious that they must have a most important influence in removing objectionable impurities. The number of excrements of Entomostraca in the recent mud of such rivers as the Thames is most surprising. In one specimen from Hammersmith, I found that there were more than 20 000 per grain; and the average number at Erith in August, 1882, was about 7 000, which is equivalent to about 200 000 per gallon of water at half ebb, from the surface to the bottom. This enormous number must represent a very large amount of sewage material consumed as food; and though, as in the case of larger animals, a considerable part of their excrements no doubt consists of organic matter capable of putrefaction, yet there can be no less doubt that the amount entirely consumed in the life-processes of these animals is also great.

As named above, I kept Cyclops alive for many months by feeding them on human excrement. It is thus easy to understand why, when they abound in the Thames, the relative amount of human excrement is very considerably less than in the winter, when their number must be much smaller. We thus appear to be led to the conclusion that when the amount of sewage discharged into a river is not too great, it furnishes food for a vast number of animals, which perform a most important part in removing it. On the contrary, if the discharge be too great, it may be injurious to them, and this process of purification may cease. Possibly this explains why in certain cases a river which is usually unobjectionable may occasionally become offensive. It also seems to make it clear that the discharge of rather too much sewage may produce relatively very great and objectionable results.

Though such comparatively large animals as Entomostraca may remove much putrefiable matter from a river, we cannot suppose that, except incidentally, they remove such very minute objects as disease-germs; but it would be a subject well worthy of investigation to ascertain whether the more minute infusoria can, and do, consume such germs as a portion of their food. If so, we should be able to understand how living bodies, which could resist any purely chemical action likely to be met with in a river, could be destroyed by the digestive process of minute animals. Hitherto, I have had no opportunity for examining this question critically, but have been able to learn certain facts, which at all events show that it is well worthy of further examination. It is only during the last month that I have paid special attention to the number of larger infusoria and various other animals of similar type met with in the waters of rivers and the sea, which can be seen and be counted by means of a low magnifying power. At low water in the Medway above Chatham, in the first half of June, the average number per gallon has been about 7 000, but sometimes as many as 16 000. Their average size was about $\frac{1}{1000}$ inch. Possibly the number of still more minute forms may be equally great; but if we confine our attention to those observed, we cannot but conclude that their effect in removing organic matter must be very considerable. Judging from what occurs in the case of larger animals, those $\frac{1}{1000}$ of an inch in diameter may well be supposed to consume as food particles of the size of germs. Up to the present time, I have however collected so few facts bearing on this question, that it must be regarded as a suggestion for future inquiry.

So far I have referred exclusively to the effect of animal life. Minute plants play an important part in another way. The number per gallon of suspended diatoms, desmids and confervoid algæ is in some cases most astonishing, and they must often produce more effect than the larger plants. As far as I have been able to ascertain, their number is to some extent related to the amount of material in the water suitable for their assimilation and growth. In the mud deposited from pure rivers their number is relatively small, but in the district of the Thames, where the sewage is discharged, I found that in summer their number per grain of mud at half-ebb tide was about 400 000, which is equivalent to about 5 000 000 per gallon of water. This is two or three times as many as were found higher up or lower down the river, and out of all proportion more than in the case of fairly pure rivers like the Medway. Their effect in oxygenating the water must be very important, since when exposed to the light, they decompose carbonic acid and give off oxygen, under circumstances most favorable for supplying the needs of animal life, and counteract the putrefactive decomposition so soon set up by minute fungi when oxygen is absent.

Taking all the above facts into consideration, it appears to me that the removal of impurities from rivers is more of a biological than a chemical question; and that in all discussions of the subject, it is most important to consider the action of minute animals and plants, which may be looked upon as being indirectly most powerful chemical agents.

[Excerpted from the Journal of the Royal Microscopical Society, 1884, pp. 988–991.]

A number of photographs of the animal forms referred to in this discussion were submitted, from which Plates Nos. VI to IX have been prepared.

DESCRIPTION OF PLATES.

Plate VI.

An instantaneous photograph ($\frac{20}{1}$) of a living colony of *Lacinularia socialis.*

Plate VII.

A mature female *Daphnia pulex* ($\frac{30}{1}$) with eggs.

Plate VIII.

Fig. 1, $\frac{8}{1}$. Mature *Gammarus.*

Fig. 2, $\frac{20}{1}$. Female *Cyclops* with egg sacs.

Fig. 3, $\frac{34}{1}$. *Cypris.*

Plate IX.

Fig. 1, $\frac{30}{1}$. *Sida crystallina.*

Fig. 2, $\frac{30}{1}$. *Chydorus.*

Fig. 3, $\frac{21}{1}$. Female *Simocephalus* carrying eggs.

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Streams.

$\frac{20}{1}$

Photo-Micrograph by
Dr. J. EDW. LINE.

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Photo-Micrograph by
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Fig. 1. $\frac{8}{1}$

Fig. 2. $\frac{20}{1}$

Fig. 3. $\frac{34}{1}$

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Fig. 1. $\frac{30}{1}$

Fig. 2. $\frac{30}{1}$

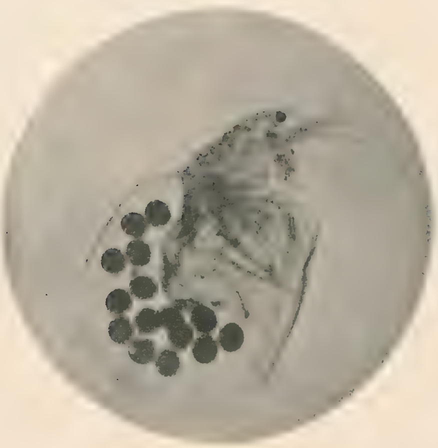

Fig. 3. $\frac{21}{1}$

Photo-Micrograph by
GEO. W. RAFTER.

S. Whinery, M. Am. Soc. C. E.—It seems well enough established that polluted river-water tends to become purified when subjected to the influences brought about by the flow of the water, such as agitation, aërification and time; but the exact conditions under which this purification takes place seem not at all well understood.

We have a mass of testimony, collected by different observers, upon different rivers, which seems to show that in some cases very impure water becomes safe for domestic use after a flow of less than twenty miles, while in other cases the impurities are still present in dangerous amount after a flow of ten times that distance. It is possible, but not probable, that there is actually so great a difference in results as recorded observations seem to show. It is much more likely that the value of such observations is impaired, by the failure on the part of observers to secure the necessary uniform conditions under which the observations should be made. The sewage which pollutes a stream is often all discharged into it at one point, and very generally on one side only of the stream. In most cases it does not become at once fully commingled with the whole volume of water, and may not become so for a long distance below the source of pollution.

We know that the waters of two confluent rivers may flow side by side for many miles, before each loses its identity. Besides, rapids and eddies or whirlpools, may operate to concentrate the impurities at certain points more that at others. It is therefore to be expected that unless observations are made with the greatest care, and in sufficient numbers, and at a sufficient number of points to give correct averages, great variations and contradictory results will be obtained.

In view of these facts, it would seem that the simple plan of conducting experiments on small artificial bodies of water, where the conditions could be controlled and made uniform, would have suggested itself to specialists in this line of investigation; but if this has ever been done, I am unable to find records of the results.

It would seem practicable to make a series of experiments and observations on a small body of contaminated river-water, confined in a vessel or tank, where all the conditions of a flowing river might be so closely imitated as to make the results applicable to the river itself. It would be easy enough to provide means of artificial agitation, corresponding very closely to the current of the river, and to vary the rate of flow or agitation at will; to imitate very closely the form of cross-section and composition of the banks of the natural stream; to study the effects of sunlight and shade, and the influence of heat and cold; to determine whether sediment, in sinking to the bottom, carries with it any considerable amount of impurities or disease-germs, and to study any other phenomena connected with the problem. It ought to be possible in this way to determine with some degree of certainty, in what length of time, under the various conditions, contaminated water becomes pure enough for domestic use. Also to study the effect of artificial methods of purification under definite conditions. The water in such a vessel or tank could be easily kept so completely commingled, that a few samples under the microscope would give reliable averages.

It might not be practicable to conduct all the experiments at one place, since the transportation of a sample of water from any great distance, might change its normal condition as taken from the river, but the apparatus could be readily moved from place to place as required. To one who is not a specialist in this line of work, it would seem practicable to attain results with a small expenditure of time and money, of far more value than desultory and uncertain tests of the waters of all the rivers in the country.

Dr. Currier.—Considering brevity as of the first importance, the author has, in the article discussed, given in the fewest words the result of voluminous reports of experiments. In the body of the communication will be found anticipatory answers, however brief, to nearly all of the very many questions put on the evening of November 5th, and to most of the inquiries and statements of those who spoke at the meeting of November 19th, in so far as these related to the subject-matter of the paper.

The allusions to the weighty facts and figures which the supporters of Pettenkoffer's theory produce, were made to show that the "drinking-water theory"—which the author is disposed to favor—is not the only one accepted by sanitarians. These great problems are at best very complex, and not so easily settled as extremists assume. The writer would distinctly state that he believes the harmfulness of polluted water to depend upon the fact that it contains harmful bacteria. No bacteriologist, believing in Koch's doctrines, would hesitate to give preference (so far as the particular sample is concerned) to a drinking-water having a considerable number of harmless bacteria, rather than to one having fewer bacteria, which were, however, of a distinctly infectious kind. We may doubt whether the healthy alimentary tract, is vulnerable to the bacteria of disease which are too often contained in drinking-water. It is presumably essential (at least in the majority of cases) that some departure from the state of perfect health of the mucous membrane must exist, in order that, for example, the typhoid bacillus shall, when swallowed, enter the system and produce disease. Yet it is the part of prudence for all to avoid the use of infected water. The introduction of the bacteria of putrefaction and decomposition with our food and drink, is in no wise desirable. The presence of these micro-organisms in the intestine tends to cause the evolution of undesirable gases, by their action upon the substances present; while the amount of salutary digestive potency which they possess, is very unimportant. They are vastly inferior in this respect to the normal digestive secretions.

As for the unusually large number of bacteria found present in the Delaware River, it may be repeated that the copious rains had washed much matter into the streams, and with it many bacteria. A more careful reading of the article would perhaps cause the querist to find the statement, that "one should not infer that the increase of 'typhoid' in Philadelphia was caused by the bacteria which had survived the 100-mile passage down the river." The stream flowing through the old Croton Aqueduct seemed a desirable one to test, since in its course it received no inflow except from the Bronx. The darkness of the conduit would not tend to lessen the number of bacteria present in the flowing water; and over the water a current of agreeable air was passing.

The results of biological examinations of water are considered most satisfactory, when the plates are prepared immediately after the sample is taken. Transportation to a distant laboratory, especially if the water is kept warm, may result in great increase. The high numbers which Professor Leeds found in the waters of the Passaic may have been due to the fact that he failed to plate the water as soon as his samples were taken from the stream. He must admit that Philadelphia would have a purer water supply, if the Delaware River received no contamination whatsoever between the "Water Gap," and the place whence it now draws a large portion of its supply from that river.

That harmful bacteria survive (at least occasionally) a passage of several miles down a stream, seems probable from the facts presented by the recent epidemic of typhoid fever at Albany. There the cases appeared to be almost entirely limited, to the districts where water from the Hudson River was drunk. (See New York papers of January 24th, 1891.)

It certainly is of vital importance, to keep the water-sheds from which we draw our supplies as free from all contaminations as we possibly can. "Only by vigilant and intelligent efforts can lasting and constant purity of the supply be maintained." The Croton supply is a comparatively "excellent water." This is shown by repeated bacteriological and chemical examinations, and furthermore by the very small number of cases of typhoid fever occurring, among those who regularly drink the New York hydrant water.

The author realizes how desirable it is that numerous observers make many examinations of various waters, and that these be frequently repeated through a long period of months or years. Such investigation involves a vast amount of systematized work and a liberal outlay. It is to be hoped that other wealthy States follow the example of Massachusetts in this respect. The results thereby obtained would be of great value.

[Dr. Currier's paper is summarized on page 40.]